Y 3. N88 : 25 / 2674

NUREG/CR-2674
ORNL/TM-8309

ornl

OAK RIDGE NATIONAL LABORATORY

UNION CARBIDE

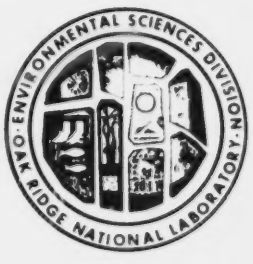
ORIGINAL
COMPLETED

Methods to Assess Impacts on Hudson River Striped Bass: Final Report

S. W. Christensen
D. S. Vaughan
W. Van Winkle
L. W. Barnthouse
D. L. DeAngelis
K. D. Kumar
R. M. Yoshiyama

ENVIRONMENTAL SCIENCES DIVISION
Publication No. 1978

Prepared for the
Division of Health, Siting, and Waste Management
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Under Interagency Agreement No. DOE 40-550-75



OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161

Available from

GPO Sales Program
Division of Technical Information and Document Control
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

NUREG/CR-2674
ORNL/TM-8309
Distribution Category-RE

Contract No. W-7405-eng-26

METHODS TO ASSESS IMPACTS ON HUDSON RIVER STRIPED BASS: FINAL REPORT

S. W. Christensen, D. S. Vaughan, W. Van Winkle, L. W. Barnthouse, D. L. DeAngelis, K. D. Kumar, and R. M. Yoshiyama

ENVIRONMENTAL SCIENCES DIVISION
Publication No. 1978

Manuscript Completed - May 1982
Date Published - June 1982

Prepared for Dr. P. Hayes, Project Representative
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
Under Interagency Agreement No. DOE 40-550-75

NRC FIN B0165

Task: Methods to Assess Impacts on Hudson River Striped Bass

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

BLANK PAGE

ACKNOWLEDGMENTS

We thank Drs. G. F. Cada and P. Kanciruk for their helpful comments on the manuscript.

BLANK PAGE

ABSTRACT

CHRISTENSEN, S. W., D. S. VAUGHAN, W. VAN WINKLE, L. W. BARNTHOUSE, D. L. DEANGELIS, K. D. KUMAR, and R. M. YOSHIYAMA. 1982. Methods to assess impacts on Hudson River striped bass: Final report. ORNL/TM-8309 and NUREG/CR-2674. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 88 pp.

This report is a description of research conducted under the U.S. Nuclear Regulatory Commission (NRC) Task "Methods to Assess Impacts on Hudson River Striped Bass." Research topics were inspired by adjudicatory hearings concerning the effects of power-generating facilities on Hudson River fish populations, principally striped bass. These hearings, involving at times the U.S. Environmental Protection Agency (EPA), Region II, as well as the NRC, spanned a nine-year period and dealt with state-of-the-art ecological issues related to entrainment and impingement.

Two young-of-the-year entrainment models and one impingement model are described. Several quantitative methods for evaluating entrainment mortality factors are presented, including methods for estimating the probability of mortality, for evaluating biases in such estimates, for detecting mortality and deriving confidence intervals, and for treating sublethal effects and indirect mortality. Biological compensation was a key issue in the hearings. A critique of the Lawler, Matusky and Skelly (LMS) compensation function, the development of a new stock-recruitment model which combines two classical models, a technique for validating stock-recruitment curve fits, and a regression analysis of stock-recruitment relationships in three fish populations are discussed. The use of discriminant analysis to estimate the relative contribution of the Hudson River striped bass population to Atlantic fisheries is described. An appendix documents the FORTRAN version of the Empirical Transport Model.

BLANK PAGE

SUMMARY

The objective of this project was to develop and apply quantitative methods for assessing the effects of power plant entrainment and impingement on the Hudson River striped bass population. Our work dealt primarily with four interrelated aspects of this assessment problem: (1) young-of-the-year models; (2) mortality of entrained eggs, larvae, and juveniles; (3) projection of long-term impacts using compensatory functions or stock-recruitment models; and (4) relative contribution of the Hudson River stock to the Atlantic coastal striped bass population. The work was done in conjunction with Nuclear Regulatory Commission and Environmental Protection Agency (Region II) adjudicatory hearings which included these four topics.

Three young-of-the-year models were developed. The first was a daily transient (tidal-averaged), longitudinally one-dimensional (cross-section-averaged) hydrodynamic simulation model (STRIPE) for striped bass young-of-the-year life stages. This model treated both entrainment and impingement of the early life-stages. It produced as output the predicted fractional reduction in year-class abundance, either with or without biological compensation. One difficulty with this or any other hydrodynamic model when applied to early life stages of fish is that fish do not behave as solute particles. Hence, their distributions according to the model correspond very poorly to sample data unless modifications are made to the model. A set of convective transport defect flux terms were incorporated into the model, which with sufficient adjustment greatly improved the fits to sample distribution data. Even so, the quality of the fits was arguable, and it seemed likely that a "battle of models" would occur which would simply cloud more relevant issues. This situation, together with the general difficulty of applying such complex hydrodynamic models, spurred the development of a set of empirical models.

Two such young-of-the-year models, denoted as the Empirical Transport Model and the Empirical Impingement Model, were developed to estimate the impacts of entrainment and impingement on striped bass year-class abundance in the Hudson River. These models make intensive use of data on abundance, distribution, and natural mortality of susceptible striped bass life stages. As a consequence, physicochemical data are not required by either model, and no hydrodynamic transport equations are employed. The impacts are computed in the form of conditional entrainment and impingement mortality rates, which are numerically equivalent to fractional reductions in year-class abundance due to entrainment and impingement in the absence of compensation. The outputs from the two models can be readily combined to provide estimates of the overall entrainment and impingement impact of power plants on striped bass year-class abundance.

The primary objective of the work on entrainment mortality was to provide life-stage-specific mortality factors as input for the Empirical Transport Model. Four aspects of the problem were investigated: (1) methods to evaluate biases in mortality estimates were developed; (2) work was begun on a technique for analyzing the sensitivity of formulae used to estimate entrainment mortality to variations in the relevant biological parameters; (3) an investigation of the statistical power of tests used to detect entrainment mortality was performed; and (4) initial laboratory experiments were performed to investigate sublethal effects of heat shock on entrained striped bass larvae.

Stock-recruitment theory has been advocated as a means of assessing the "compensatory reserve" of fish populations. This would provide a means of projecting the implications of conditional mortality rates from young-of-the-year models to adult fish populations and fishing yields. Three aspects of stock-recruitment analysis were investigated: (1) a new stock-recruitment model was developed, which combined the classical Ricker and Beverton-Holt models; (2) an empirical approach to validating fits of the Ricker stock-recruitment model to data from a population of mutliple-aged spawners was developed and applied to data from the Hudson River striped bass population; and (3) three approaches to stock-recruitment analysis were compared, using data from several populations, including the California striped bass population. In addition, a sensitivity analysis was performed on a compensation function used by utility consultants.

The relative contribution of the Hudson River striped bass stock to the 1975 Atlantic coastal population was investigated. An analysis originally performed by Texas Instruments Incorporated (TI) was evaluated and then refined. It was concluded that the five-year-old fish that dominated TI's coastal samples originated almost entirely in the Chesapeake, as part of the unusually strong 1970 Chesapeake year class. The Hudson River contribution by age class varied between nearly 0 and approximately 30%.

TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS	iii
ABSTRACT	v
SUMMARY	vii
LIST OF FIGURES	xi
1. INTRODUCTION	1
2. YOUNG-OF-THE-YEAR MODELS	2
2.1 Introduction	2
2.2 STRIPE	2
2.3 Empirical Transport Model	6
2.4 Empirical Impingement Model	9
3. QUANTITATIVE METHODS FOR ESTIMATING PROBABILITY OF ENTRAINMENT MORTALITY	13
3.1 Introduction	13
3.2 Sublethal Effects and Indirect Mortality	17
3.3 Biases in Estimates of the Entrainment Mortality Factor	19
3.3.1 Quantitative methods for estimating the probability of entrainment mortality	19
3.3.2 Additional biases in estimates of the entrainment mortality factor	25
3.4 Detectability and Precision of Estimates of the Entrainment Mortality Factor	27
3.5 Effects of Variation on Estimates of the Entrainment Mortality Factor	30

Page

4. BIOLOGICAL COMPENSATION AND STOCK-RECRUITMENT THEORY 32

4.1 Introduction 32

4.2 Critique of the LMS Compensation Function 33

4.3 Development of a Stock-Progeny Model for Assessing Power Plant Effects on Fish Populations 34

4.4 Stock-Recruitment Model Validation 37

4.5 Regression Analyses of Stock-Recruitment Relationships in Three Fish Populations 41

4.5.1 Striped bass 42
4.5.2 Atlantic menhaden 42
4.5.3 American shad 43

5. RELATIVE CONTRIBUTION AND DISCRIMINANT ANALYSIS 45

6. CONCLUSIONS AND RECOMMENDATIONS 46

7. REFERENCES 48

APPENDIX A: USER'S GUIDE FOR THE FORTRAN IV VERSION OF THE EMPIRICAL TRANSPORT MODEL (ETM) 55

APPENDIX B: PUBLICATIONS, PRESENTATIONS, AND TESTIMONY 67

LIST OF FIGURES

Figure		Page
2.2-1.	Schematic representation of a discrete element for the conceptual development of STRIPE	4
3.1-1.	Diagrammatic representation of the intake sampling process for entrainment mortality estimation at a power plant	15
3.1-2.	Diagrammatic representation of the discharge sampling process for entrainment mortality estimation at a power plant	16
3.3.1-1.	Comparison of f-factor estimates from the ORNL formula and the OTHER formula, assuming no gear avoidance, no extrusion or destruction of initially alive organisms, and the same degree of extrusion of initially dead oganisms and of gear mortality at intake and discharge sampling stations	21
3.3.1-2.	Comparison of f-factor estimates from the ORNL formula and the OTHER formula, assuming intake conditions similar to discharge conditions and all factors assigned plausible values	22
3.3.1-3.	Comparison of f-factor estimates from the ORNL formula and the OTHER formula, assuming higher velocities at the intake than at the discharge sampling station	23
3.3.1-4.	Comparison of f-factor estimates from the ORNL formula and the OTHER formula, assuming higher velocities at the discharge than at the intake sampling station	24
3.4-1.	Sample size required as a function of statistical power for three levels of the fraction alive in the intake sample (p_1), assuming an underlying entrainment mortality (f_0) of 0.5	29
4.3-1.	Two forms of classical stock-recruitment (reproduction) curves: (a) the Beverton-Holt-type curve and (b) the Ricker-type curve	35
4.4-1.	Results from Replicate 1 and part of Replicate 2 for Case 102, Run 933 - the proxy test case with alpha of 1.25 and random variation in young-of-the-year mortality	40

1. INTRODUCTION

The overall objective of this Nuclear Regulatory Commission (NRC) project was to develop and apply computer simulation models and other methods of quantitative analysis to assess the effects of power plant entrainment and impingement on the striped bass population in the Hudson River.

Most of the work done under this project was directly related to adjudicatory hearings on the Hudson River Power Case, Environmental Protection Agency (EPA), Region II. Scientists from the Oak Ridge National Laboratory (ORNL) (L. W. Barnthouse, S. W. Christensen, W. Van Winkle, and D. S. Vaughan) were heavily involved in the lengthy cross-examination of the utilities' expert witnesses. In addition, ORNL scientists (those listed above, plus K. D. Kumar) prepared a substantial portion of EPA's written testimony, which was filed on May 14, 1979. Most of the results summarized in this report were incorporated in our testimony for EPA, which was recently published in a 3-volume Nuclear Regulatory Commission (NRC) report (Boreman et al. 1982), Barnthouse et al. 1982, and Christensen et al. 1982). L. W. Barnthouse and S. W. Christensen were cross-examined on a small part of this testimony in September 1980. By this time, negotiations that had been underway for more than a year were showing signs of success. The signing of a settlement agreement on December 19, 1980, brought the adjudicatory hearings to an end (Christensen et al. 1981).

The NRC had already been involved in controversy about power plant impacts on the Hudson River in connection with its NEPA-mandated responsibility for Indian Point Units 2 and 3. The NRC assisted EPA by funding research that formed part of the technical basis for EPA's testimony, as well as assisting in the conduct of the hearing itself. This report provides a synopsis of the research funded in whole or in part by NRC under this task.

2. YOUNG-OF-THE-YEAR MODELS

2.1 Introduction

One of the areas of greatest concern about biological impacts of power plants is entrainment mortality of planktonic organisms, including fish eggs and larvae, and impingement mortality of larger organisms, principally young-of-the-year or yearling fish. Entrainment refers to the passage of organisms too small to be retained on intake screens through a power plant in the condenser cooling water. The water and the organisms contained in it are heated as they pass through the heat exchange system, and remain at a higher temperature until discharged back into the water body. There is also mechanical stress, and sometimes chemical stress, associated with the entrainment process. Impingement refers to the trapping of older, larger fish on the screens used to remove debris from the pumped water.

Young-of-the-year models are mathematical models which estimate the direct impact of entrainment and/or impingement on fish populations. The estimation is said to be of direct impact because these models do not deal with the total impact, which is manifest only after the direct entrainment-impingement impact has propagated through the entire life-cycle. This life-cycle aspect of impact is usually evaluated using life-cycle models or some other approach. Two such approaches, compensation functions and stock-recruitment analysis, are discussed in Section 4 of this report.

We have developed entrainment and impingement models based on two somewhat contrasting approaches to the problem: hydrodynamic simulation (STRIPE) and empirical calculation [the Empirical Transport Model (ETM) and Empirical Impingement Model (EIM)]. Each of these models is discussed individually.

2.2 STRIPE

Our first model was a daily transient (tidal-averaged), longitudinally one-dimensional (cross-section-averaged) computer simulation model ("STRIPE") for the assessment of the entrainment and impingement impacts of power plant operations on young-of-the-year populations of the striped bass, Morone saxatilis, in the Hudson River (Eraslan et al. 1976).

The model considers six life-stage populations (i.e., egg, yolk-sac larva, post-yolk-sac larva, Juvenile I, Juvenile II, and Juvenile III). The choice of the particular life stages and their associated durations is based on information from the literature and from sampling programs in the Hudson River relating to the morphological, physiological, and behavioral characteristics of the striped bass early life history stages. The transfer of populations

from earlier to later life stages is formulated in terms of apparent survival probabilities of life-stage populations and timewise continuous coefficients for growth and mortality rates. The continuous property of the formulation enables the model to represent realistically the simultaneous existence of different life-stage populations in the river.

To incorporate the existence of various mechanisms for biological compensation which might in part affect the young-of-the-year populations in the river, the formulation includes multiplicative factors which can separately vary the apparent survival probabilities, growth rate coefficients, and mortality rate coefficients of each life stage as a function of the population density of that life stage.

The dependence of various biological characteristics of the life stages on temperature and salinity is also considered in the model. The necessary information for the physical conditions is included as input data in the form of daily transient, longitudinal distributions of temperature and salinity along the river.

The model considers 244.6 river kilometers of the Hudson River estuary from the Troy Dam to the Battery (Manhattan). This length is segmented into 76 discrete elements, each 3.22 km in length (Fig. 2.2-1). The high spatial resolution assures the necessary accuracy in specifying the existing morphological characteristics and the flow conditions in the river which can affect the distributions of the life-stage populations and hence the conditions of entrainment and impingement at the power plants. The input data for the important geometric properties of the discrete elements (i.e., area, volume, depth, and surface width) are determined using appropriate transect profiles obtained from maps of the Hudson River.

The mathematical algorithm governing the model is based on the tidal-averaged and cross-section-averaged forms of the conservation principles for the water mass and the population number of each life stage in each discrete element. Consistent with the tidal-averaged assumption of the model, the longitudinal convective transfer of the life-stage populations is formulated in terms of the local net freshwater flow in the river. The necessary input data for the freshwater flow are determined from the daily flow rates observed at the Troy Dam, with appropriate modifications to approximately simulate the longitudinal distributions of freshwater flow resulting from the additional runoff in the Hudson River Basin.

Based on the physical conditions in the river and the biological characteristics of the striped bass young-of-the-year populations, the overall longitudinal transport phenomenon is rigorously formulated by considering three fundamental contributions: (a) tidal dispersion transport, (b) convective defect transport, and (c) migratory transport.

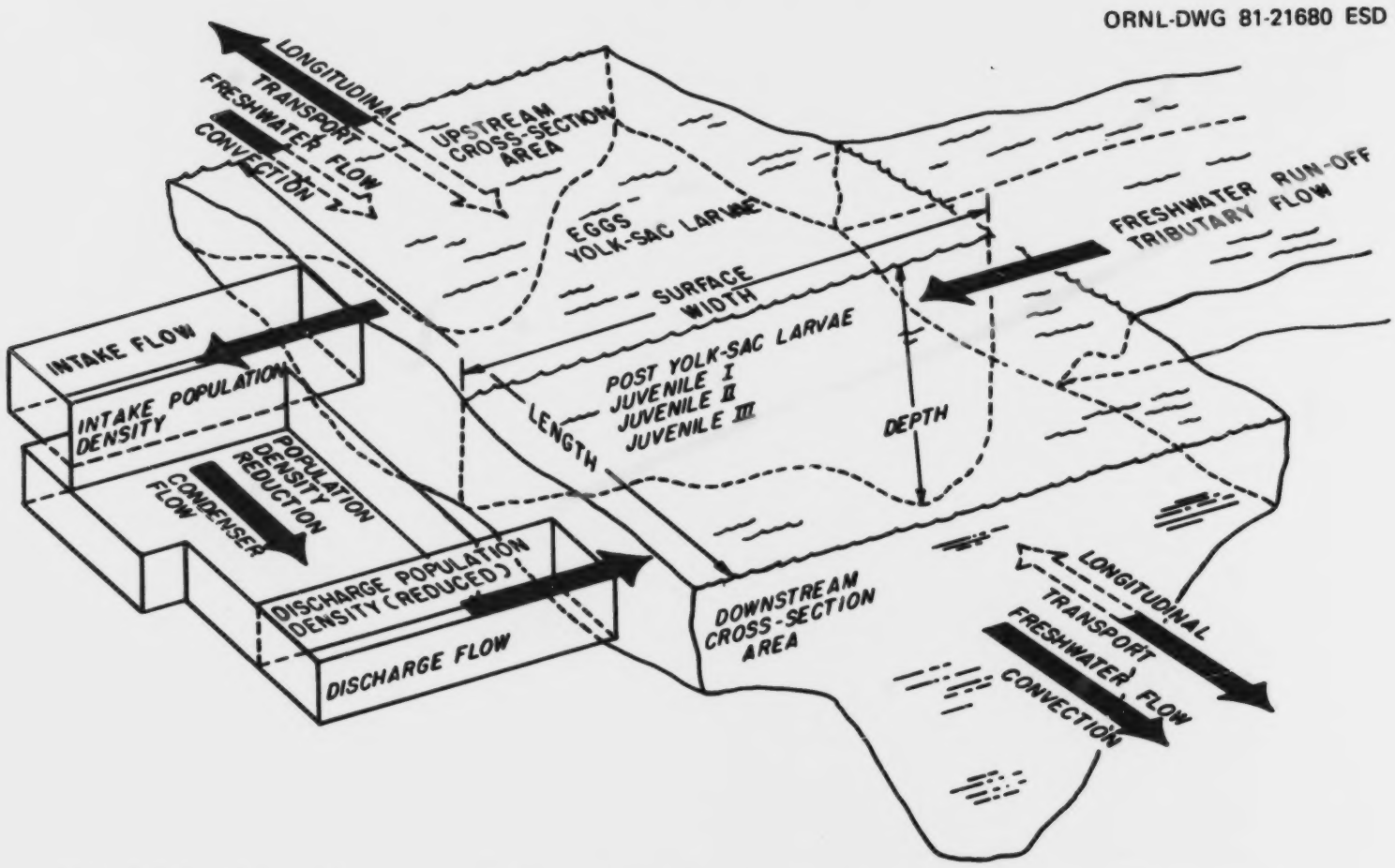


Fig. 2.2-1. Schematic representation of a discrete element for the conceptual development of STRIPE. Source: USNRC 1975.

The tidal dispersion transport is formulated as though the organisms were passive. This approach determines the tidal-averaged longitudinal transport fluxes resulting from the vertical turbulent eddy diffusion phenomenon under periodic tidal flow conditions in an estuary. The ultimate longitudinal effects of the actual nonuniform distributions in the vertical and lateral directions of the axial velocity component and of the life-stage population densities result in a decreased net rate of movement downstream of the early life-stage populations. To simulate this aspect, convective defect transport fluxes were included in the model. The associated coefficients were determined for each age group, based on a parametric study to obtain the best simulations of the observed 1973 longitudinal distributions of the life-stage populations in the river.

The longitudinal transport due to the migration of the juvenile life stages to the shoal areas along the estuary is modeled according to a formulation that represents a balance between the effects of shoaling preference and overcrowding. The representative geometric parameter for indicating the relative abundance of shoaling areas in a discrete element is defined as the ratio of the surface width to the maximum depth averaged over the 3.2-km (2-mile) length of the element. This parameter is calculated from the detailed transect cross-sectional data for the estuary. The longitudinal migratory transport flux of a life stage is formulated as a linear combination of the gradient of shoal paramater and the gradient of the population density of the life stage.

Rates of reduction of life-stage populations by entrainment and impingement at the power plants are formulated by considering (a) differences between population densities entering the intakes and average densities in the discrete elements, (b) avoidance factors (for juveniles) based on temperature- and salinity-dependent mobility characteristics, (c) geometric factors for the intakes and the discharges (i.e., possible aspects of design or location which could further modify densities), and (d) temperature-dependent survival probabilities of the life stages upon passage through the cooling water system of the power plants.

The general mathematical formulation of the model is a semidiscrete system of moderately coupled, quasi-linear ordinary differential equations for the densities of the life-stage populations in the discrete elements. It is numerically integrated by a fourth-order Runge-Kutta-Gill scheme with a time-step size based on a rigorous stability criterion for explicit finite difference methods. Initial conditions for the model are specified either as (a) no young-of-the-year population in the estuary, corresponding to conditions at the start of the spawning period; or (b) for restart computational runs, life-stage population densities in all discrete elements, corresponding to longitudinal distributions in the river after spawning. The numerical solutions are obtained as extensions of the initial conditions to represent daily averaged population densities for all life stages in all discrete elements.

The model was employed to simulate striped bass young-of-the-year populations from May through October 1973. Sufficient data for 1973 are available to represent physical and biological conditions in the Hudson River; the May-October period was selected, because entrainment impact, which is of greater magnitude and concern than impingement impact, is confined to this period. Comparisons of numerical solutions from the model with summaries of 1973 data indicate that the model is acceptable both from qualitative and quantitative considerations for simulating temporal and longitudinal distributions of the life-stage population densities in the estuary. Certain discrepancies between the computer simulations and the observed data for temporal variations of net standing crops of life stages in the river suggest inadequacies and inconsistencies in the sampling and reduction of the 1973 data.

A FORTRAN listing of the associated computer code STRIPE is presented in the Appendix of Eraslan et al. (1976). Sample outputs are included to illustrate various available forms of presentation of the numerical solutions. In addition, a user's manual has been prepared (Eraslan et al. 1982), which includes a summary of the computational equations; subroutine descriptions and flowcharts; information on program input, output, and implementation; a program listing and glossaries of variables; documentation of additional output subroutines; and sample case input and output.

The primary application of this computer simulation model was in the Final Environmental Statement for Indian Point Unit 3 (USNRC 1975). The high quality of this impact statement, and in particular the application of this model, played a role in the NRC, Consolidated Edison Company of New York, and the Intervenors signing a settlement agreement as opposed to engaging in lengthy adjudicatory hearings as had occurred in the licensing proceedings for Indian Point Unit 2. STRIPE has not been used by the NRC, Oak Ridge National Laboratory, Consolidated Edison Co., or the New York Power Authority since 1975, and it is not anticipated that the code will be used in the future. However, certain parts of the model continue to be used or referenced (Swartzman et al. 1978).

2.3 Empirical Transport Model

The Empirical Transport Model (ETM) (Boreman et al. 1978, Boreman et al. 1981) is a generalized mathematical model that incorporates empirically derived organism distribution and movement characteristics to estimate the conditional entrainment mortality rate. The generalized model is formulated as follows:

$$m_T = 1 - \frac{\sum_{s=1}^{S} N_0 R_s \left\{ \prod_{j=0}^{J} \left[\sum_{k=1}^{K} D_{s+j,jk} e^{-(M_{s+j,jk}+E_{s+j,jk})t} \right] \right\}}{\sum_{s=1}^{S} N_0 R_s \left\{ \prod_{j=0}^{J} \left[\sum_{k=1}^{K} D_{s+j,jk} e^{-(M_{s+j,jk})t} \right] \right\}} \qquad (2.3\text{-}1)$$

where: m_T = total conditional entrainment mortality rate,

N_0 = total number of eggs spawned,

s = week of spawning period,

S = total number of weeks in spawning period,

R_s = proportion of eggs spawned during week s,

j = age 0, 1, 2, . . ., J,

J = oldest entrainable age,

k = region 1, 2, 3, . . ., K,

K = total number of regions within the water body,

$D_{s+j,jk}$ = proportion of total standing crop of age j individuals during week $s+j$ in region k,

$M_{s+j,jk}$ = instantaneous natural mortality rate constant of age j individuals during week $s+j$ in region k (units: per day),

$E_{s+j,jk}$ = instantaneous entrainment mortality rate constant of age j individuals during week $s+j$ in region k (units: per day), and

t = duration (in days) of week $s+j$.

In this formulation, the numerator of the term on the right side of the equation is the total probability of survival for the population when exposed to both natural and entrainment mortality; the denominator is the probability of survival from natural causes only. Both rates of mortality are time-, space-, and age-specific. The model can be simplified by making various assumptions. For example, if natural mortality is assumed to be a function only of age, then the generalized equation can be simplified to:

$$m_T = 1 - \left\{ \sum_{s=1}^{S} R_s \left[\prod_{j=0}^{J} \sum_{k=1}^{K} D_{s+j,jk} e^{-(E_{s+j,jk})t} \right] \right\} \qquad (2.3\text{-}2)$$

Note that with the simplifying assumption, estimates of age, spatial, and temporal variations in natural mortality are not required for estimation of the conditional entrainment mortality rate.

The input data needed for the ETM include geographic regions within the water body to define the distribution and movement of

organisms while they are vulnerable to entrainment, estimates of physical factors (water volume and power plant intake flow in each region), entrainment susceptibility in each region for the various life stages present as a function of calendar time, the time that organisms will be vulnerable to entrainment, and the distribution of life stages among the regions of the water body as a function of calendar time.

The effect of organism movement patterns is incorporated by the variable D in the model. Given sufficient data, the actual spatial and temporal distributions of the various ages of the organisms, as determined through field sampling, can be used to define D. The value of this approach is that it relies on observed movement patterns rather than on complex simulations of incompletely understood mechanisms of organism distribution, which are often unable to adequately replicate distributions observed in the field. A disadvantage of this approach is that it requires an extensive and detailed set of observations throughout the period of occurrence of the entrainable life stages of the population in question.

If sufficient observational detail is lacking to define the values of D as a function of both organism age and calendar time, then field data can be processed to provide a seasonally averaged distribution as a function of organism age or life stage. The adequacy of this and other simplifications can be studied by sensitivity analyses which allow the user to ascertain the relative importance and probable direction of error that might be introduced by the simplification processes.

The two most important limitations of the application of the ETM are related to the acquisition and processing of field data. The first lies in the inability of current technology to separate the processes of mortality and movement of entrainable organisms. If natural mortality varies spatially, then changes in observed distributions of organisms are caused by both movement and differential mortality among regions of the water body. This complication may or may not be important, depending on the magnitude of the spatial variation in mortality. This limitation applies to all models that have been proposed to estimate entrainment impacts. As such, the user should carefully evaluate the probable impact of entrainment mortality on the observed distributions, because projections of conditional mortality rates are likely to be overestimated for preoperational studies and underestimated for postoperational studies. These tendencies may exist because of a localized depletion of organisms due to entrainment mortality.

The second limitation is that the model uses distribution data collected under specific conditions. Such conditions vary from year to year. As a consequence, several years of data are needed to establish the probable variation that would occur in the input variables and hence provide a range of conditional entrainment mortality rate estimates for predictive purposes.

These limitations preclude the use of this or other models to "measure" the actual conditional entrainment mortality rate. Such an ability is beyond the present state-of-the-art. However, the ETM can be used where sufficient data are available as a tool for directly estimating the entrainment mortality rate without the uncertainties imposed by complex simulations of incompletely understood mechanisms of organism movements.

The ETM has been used to estimate conditional mortality rates for several fish species inhabiting the Hudson River Estuary (Boreman et al. 1982) in connection with the consolidated EPA hearing concerning power plant impacts discussed in Section 1. The model was also used extensively during settlement negotiations, and it formed a part of the framework that led to a settlement agreement. In addition, the ETM has been or is being used elsewhere.

2.4 Empirical Impingement Model

In this task the classical fishing theory developed by Ricker (1975) was applied to the problem of estimating the fractional reduction in year-class abundance caused by the impingement of juvenile fish. It follows from Ricker's theory (specifically his "type II fishery") that the fractional reduction in year-class abundance due to impingement is numerically equal to the conditional impingement mortality rate, defined as the fraction of the vulnerable population that would be impinged in the absence of mortality from all other sources, both natural and anthropogenic (throughout this section we denote all background mortality as "natural" mortality). The conditional mortality rate also accounts for the differential impact of impinging fish of different ages, and when properly calculated it accounts for the effects of seasonal variations in impingement. Because of these properties, the conditional mortality rate is superior to the exploitation rate as a measure of impact.

We developed a simple empirical model, the Empirical Impingement Model, that can be used to estimate the impact, measured by the conditional impingement mortality rate, of existing power plants (or any other facilities that impinge fish) on individual species, given estimates of the initial number and the rate of total mortality of impingeable juveniles. Hydrodynamic data and information about the spatial distribution and/or migratory patterns of vulnerable populations are not required.

The model follows a single cohort from the time the fish first become vulnerable to impingement to the time at which they have grown large enough to escape impingement. Outputs from the model are the population size at the end of the period of vulnerability and the fractional reduction in population size due to impingement. Compensation during this period is assumed to be negligible.

The Empirical Impingement Model is based on Ricker's type II fisheries model (Ricker 1975). This model, restated for impingement mortality rather than for fishing mortality, is based on two assumptions:

(1) for each fish, the probabilities of death due to natural causes and due to impingement are independent, and

(2) impingement mortality and natural mortality both occur at rates that are constant over time.

With the exceptions of I and N_0, the symbols and definitions below are those of Ricker (1975). Let:

F = instantaneous rate of impingement mortality,

M = instantaneous rate of natural mortality,

Z = total instantaneous rate of mortality = $F + M$,

I = total number of fish impinged,

N_0 = initial population size,

u = impingement exploitation rate = fraction of initial population actually removed by impingement = I/N_0,

m = conditional impingement mortality rate = fraction of the initial population that would be killed by impingement in the absence of natural mortality = $1 - e^{-F}$,

n = conditional natural mortality rate = fraction of the initial population that would die of natural causes in the absence of impingement = $1 - e^{-M}$,

A = fraction of the initial population dying from all causes during the period of vulnerability $1 - e^{-Z}$ = $1 - (1 - m)(1 - n) = m+n - mn$.

The conditional impingement mortality rate is necessarily greater than the impingement exploitation rate (Barnthouse et al. 1979). Ricker (1975) presented the following equation relating the exploitation rate to the rates of total mortality and fishing (for our purposes, impingement) mortality:

$$u = \frac{FA}{Z} \quad . \qquad (2.4\text{-}1)$$

From Ricker's equation and the above definitions we derived an equation expressing m as a function of u and A:

$$m = 1 - (1 - A)^{u/A} \quad . \qquad (2.4\text{-}2)$$

Three quantities are required to calculate m using Eq. (2.4-2): the two components of the exploitation rate (i.e., the initial number of vulnerable fish and the total number impinged during the period of vulnerability) and the fraction of the initial population dying from all causes during the period of vulnerability.

However, there are situations in which it is desirable to express m as a function not of the total fraction dying of all causes, but of the conditional natural mortality rate. A formulation that separates natural and impingement mortality is useful in studying the effects of seasonal fluctuations of one or both sources of mortality. Such a formulation is also required for an important practical application: the assessment of relative impacts associated with alternative intake structures and/or alternative modes of plant operation that reduce impingement (and therefore total mortality) but do not alter natural mortality. For these purposes, Eq. (2.4-2) can be formulated in terms of conditional natural mortality simply by substituting $(m + n - mn)$ for A. In this form, Eq. (2.4-2) is transcendental, i.e., no explicit solution of the form $m = f(u,n)$ can be written. However, if the values of n and u are known, a numerical solution for m can easily be found by means of iterative substitution. Like m, n cannot be directly measured. If A and u are known, n can be calculated using an equation similar in form to Eq. (2.4-2):

$$n = 1 - (1 - A)^{(1 - u/A)} . \qquad (2.4\text{-}3)$$

Equation (2.4-3) was used by McFadden and Lawler (1977) and by Texas Instruments (1975a).

Equation (2.4-2) is strictly valid only if assumptions 1 and 2, discussed above, are true. However, violations of one or both assumptions probably are common in real fish populations. For example, contrary to assumption 1 (independence of rates) it is possible that small or weak individuals within a population are especially vulnerable to both natural and impingement mortality. If the fish impinged by power plants are those that are the least likely to survive to adulthood, then Eq. (2.4-2) will overestimate the impact of impingement. Although plausible, this phenomenon has been difficult to demonstrate. Several years of study by Texas Instruments (1974, 1975b, 1976a, 1977) failed to produce conclusive evidence that striped bass impinged at the Indian Point Generating Station are less robust than fish collected from the Hudson River in the vicinity of the plant.

Serious violations of assumption 2 (constancy of rates over time) are both common and relatively easy to document. For example, natural

mortality in young striped bass is probably higher during the summer and fall than during the colder seasons when predators are less active. Impingement, on the other hand, is highest during the winter and spring. Many examples of order-of-magnitude seasonal variations in impingement rates can be found in the data compiled by Sharma and Freeman (1977), Freeman and Sharma (1977), and Stupka and Sharma (1977).

The model was, therefore, modified to account for seasonal variations in both natural and impingement mortality. Given M, the daily instantaneous natural mortality rate (D), is equal to M/365. Monthly conditional natural mortality rates (n_i) can then be calculated as

$$n_i = 1 - e^{-d_i D} \quad , \tag{2.4-4}$$

where d_i is equal to the number of days in month i.

Using the monthly impingement totals (I_i) and monthly values of n_i, monthly values of the conditional impingement mortality rate (m_i) are calculated in sequence. We use N_0 and I_1 to calculate the first monthly exploitation rate (u_1), and then solve Eq. (2.4-2) for m_1. The initial population size for the second month is calculated as

$$N_1 = N_0 (1 - m_1)(1 - n_1) \quad . \tag{2.4-5}$$

The above calculations are repeated for each successive month and the total conditional impingement mortality rate is calculated as

$$m_T = 1 - \prod_{i=1}^{12} (1 - m_i) \quad . \tag{2.4-6}$$

The topical report entitled "An Empirical Model of Impingement Impact" (Barnthouse et al. 1979) contains a discussion of the properties of the conditional impingement mortality rate, an illustration of the model using the 1974 year class of the Hudson River striped bass population as an example, and a sensitivity analysis of the model. In addition to its application to striped bass, this model has been used to calculate conditional impingement mortality rates for white perch, Atlantic tomcod, alewife, blueback herring, and American shad year classes in the Hudson River. These applications are described in Van Winkle et al. (1980), Barnthouse and Van Winkle (1981), and Barnthouse et al. (1981).

3. QUANTITATIVE METHODS FOR ESTIMATING PROBABILITY OF ENTRAINMENT MORTALITY

3.1 Introduction

This section describes the entrainment mortality factor for power plant passage which is used as input to the Empirical Transport Model (ETM) to estimate the conditional entrainment mortality rate (Section 2.3). Entrainment is defined as the passage of organisms (e.g., fish eggs and larvae) through a power plant in the cooling water. The entrainment mortality factor, denoted as either the f-factor or simply as f, is the fraction of entrained live organisms killed as a result of passage through the plant. This mortality stems from three main sources of stress: thermal, biocidal, and physical (Schubel and Marcy 1978). The rapid rise in temperature at the condenser is followed by continued exposure to elevated temperatures until discharge to and mixing with the ambient water body. Biocides, such as chlorine gas or calcium and sodium hypochlorite, are used to control fouling organisms in the intake and condenser systems. Physical stresses include mechanical buffeting, acceleration, velocity shear forces, and changes in hydrostatic pressure. Synergistic effects may also be important (Vaughan 1979).

Entrainment mortality may be direct (immediate or latent) or indirect. Latent mortality results from the inevitable differential mortality of entrained versus control organisms due to delayed factors such as physical or physiological damage. Indirect entrainment mortality, discussed more fully in Section 3.2, results from the differential death of entrained organisms due to extrinsic factors (e.g., increased vulnerability to predators). The total f-factor is estimated by applying the following general formula (Vaughan 1979; Appendix C.1):

$$f = 1 - (1 - f_{i,D})(1 - f_{l,D})(1 - f_I) \quad . \qquad (3.1\text{-}1)$$

The term $(1 - f_{i,D})$ represents the probability of an entrained organism surviving direct entrainment based on an immediate evaluation of survival. The term $(1 - f_{l,D})$ represents the probability of surviving the direct effects of entrainment based on evaluating the survival of immediate survivors a fixed time interval, such as 24 h, after entrainment. The term $(1 - f_I)$ is the probability of surviving the indirect effects of entrainment. Combining these probabilities as shown in Eq. (3.1-1) assumes that these probabilities are independent of each other.

The biologist's problem is to use information from entrainment sampling to estimate the immediate (or latent) f-factor. While a variety of estimators were advanced for this purpose, two formulas seem to be used most frequently. Both are based on comparing the proportion

of organisms alive in the intake sample (p_1) with the proportion of organisms alive in the discharge sample (p_2). Referring to Fig. 3.1-1 or to Fig. 3.1-2, for example, the values of p_1 and p_2 are obtained as:

$$p_1 \text{ (or } p_2) = \frac{\text{ALIVE}}{\text{ALIVE + DEAD}} , \qquad (3.1\text{-}2)$$

where ALIVE is the number of live organisms in the intake or discharge collection sample and DEAD is the number of dead organisms.

The most commonly used formula for estimating the f-factor is

$$f = \frac{p_1 - p_2}{p_1} . \qquad (3.1\text{-}3)$$

This formula, termed the "ORNL" formula in this report, can produce estimates ranging from $-\infty$ to 1. Negative estimates result only from sampling error because $p_1 \geq p_2$. It was developed by ORNL (Oak Ridge National Laboratory) in the USNRC (1975) reference (also see Barnthouse et al. 1977, Section 5.3; Ecological Analysts 1977a; McFadden 1977; and Vaughan 1979, Appendix C for similar derivations) as a means of estimating the immediate (or latent) mortality upon passage through a power-plant's condenser cooling system.

The second formula which was used to quantify entrainment mortality (NYU 1973; WAPORA 1975) is

$$f = p_1 - p_2 . \qquad (3.1\text{-}4)$$

This formula, termed the "OTHER" formula in this report, can take on values ranging from -1 to 1. Once again, negative estimates result only from sampling error. It has deservedly fallen into disuse in recent years. There are no non-trivial sets of assumptions we can find which allow this formula to produce accurate estimates (although occasionally, by chance, it may produce correct estimates).

Inaccuracies (or biases) in these formulas are discussed in Section 3.3. The ability of these two formulas [Eqs. (3.1-3) and (3.1-4)] to estimate the true f-factor are compared in Section 3.3.1. Even though the ORNL formula [Eq. (3.1-3)] is generally superior to the OTHER formula [Eq. (3.1-4)] and is supported by probabilistic arguments, the ORNL formula is subject to inaccuracies (or biases) that result from biological and sampling phenomena. Section 3.3.2 describes the direction of some of these biases in f-factor estimates based on the ORNL formula that result from these biological and sampling phenomena.

ORNL-DWG 77-14392R3

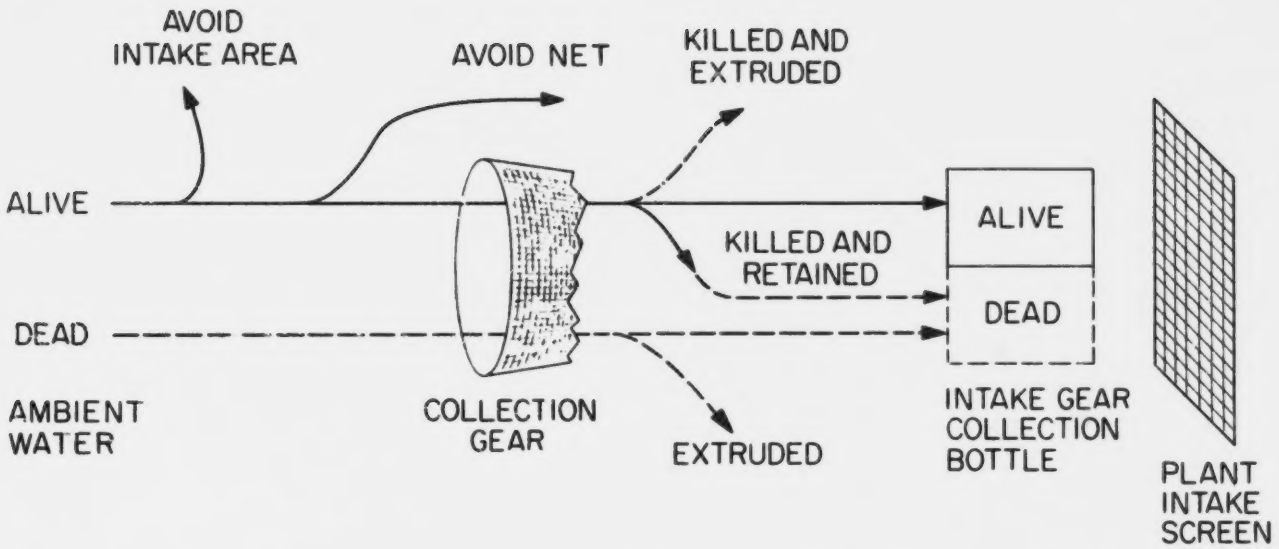


Fig. 3.1-1. Diagrammatic representation of the intake sampling process for entrainment mortality estimation at a power plant.

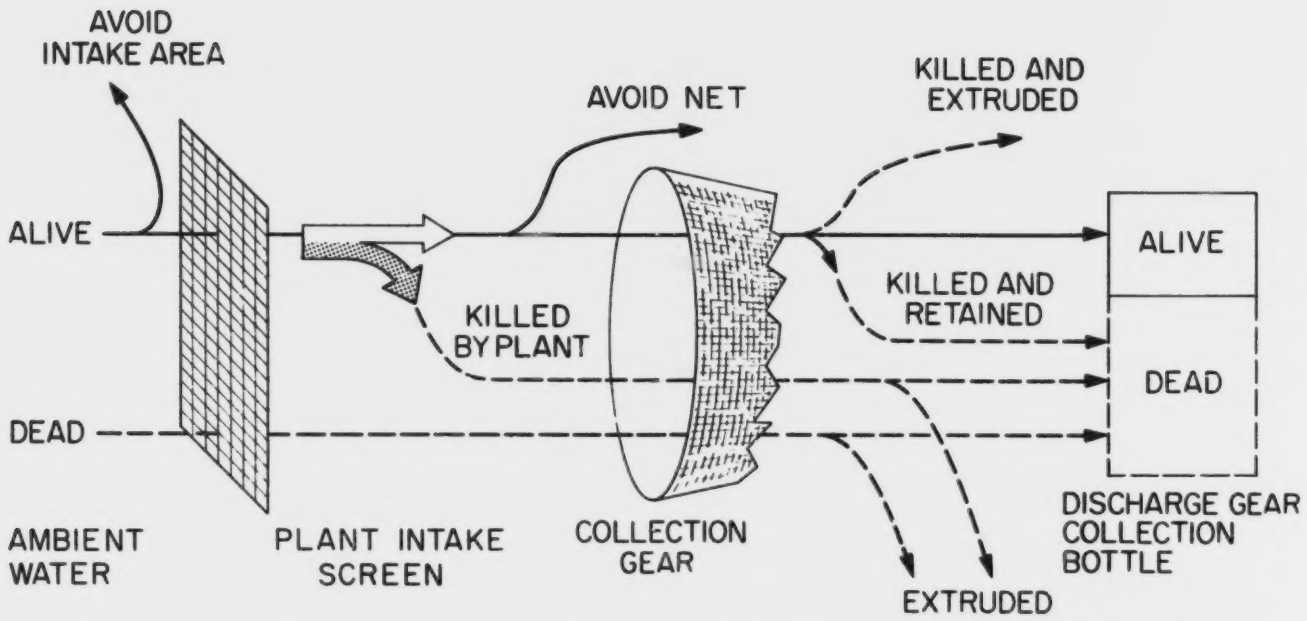


Fig. 3.1-2. Diagrammatic representation of the discharge sampling process for entrainment mortality estimation at a power plant.

In using f-factors as input to impact assessment models, it is necessary to be able to detect and develop precise estimates of the f-factor. Section 3.4 describes three desirable results obtainable from an entrainment mortality sampling program, including: (1) low minimum detectable entrainment mortality, (2) high statistical power, and (3) more precise estimates. Increasing sample sizes at both the intake and discharge sampling stations and increasing the fraction alive in the intake samples will enhance all three of these desirable results.

Finally, Section 3.5 describes the computer program ENTRAN, which is essentially a stochastic simulation model. The entrainment process is simulated repeatedly, and f-factors based on Eqs. 3.1-3 and 3.1-4 are compared to the true value of the entrainment mortality factor. The reliability of each formula can be evaluated with respect to the total error of the estimates from the true value, or the decomposition of this error into measures of bias (or inaccurracy) and variability (or lack of precision). The influence of sampling and biological phenomena on estimates of the f-factor can be explored in detail using ENTRAN.

3.2 Sublethal Effects and Indirect Mortality

In response to legal requirements involving the U.S. Environmental Protection Agency through Section 316(b) of Public Law 92-500 and the U.S. Nuclear Regulatory Commission through the National Environmental Policy Act, large amounts of data on entrainment were collected at power plants across the country in an effort to estimate the probability of mortality for an organism due to condenser passage. These efforts focused on direct mortality, namely, both immediate mortality and inevitable latent mortality[1] due to damage resulting from passage through the cooling system. As more data were collected and as sampling techniques were improved, it became increasingly obvious that direct mortality due to entrainment is considerably less than 100% in many situations (Barnthouse et al. 1977, Section 5.3; Cannon et al. 1977; Ecological Analysts 1977b, Ginn et al. 1977; Cada et al. 1981; and Jinks et al. 1981).

In addition to direct mortality, however, there is another important component of entrainment mortality. This component is termed indirect mortality, that is, mortality of organisms that survive the entrainment experience itself but die prematurely due to sublethal

[1] "Inevitable latent mortality" is the mortality that ultimately would occur, due to damage resulting from condenser passage, in latent mortality studies of arbitrarily long duration, as opposed to only 24-h or 96-h duration.

effects of entrainment. Possible sublethal effects include an increase in vulnerability to predation, disease, parasitism, or effects of toxic materials or thermal stress and a reduction in competitive ability or propensity to feed. When direct entrainment mortality is less than 100%, it is important to estimate indirect mortality.

Indirect mortality has not often been quantitatively considered in modeling entrainment impacts at the population level. With two exceptions (Barnthouse et al. 1977, Section 5.3; USNRC 1975, pp. V-87 to V-87), it has been assumed implicitly that indirect mortality is negligible. Consequently, if it is not negligible, model forecasts of entrainment impact on fish populations will underestimate the actual impact.

The objectives of this work which is discussed in more detail is Van Winkle et al. (1979) were (1) to derive an equation for the conditional mortality rate due to a stress that incorporates both direct and indirect mortality; (2) to present results from preliminary experiments to test for sublethal effects of heat shock on the feeding of striped bass (Morone saxatilis) larvae; (3) to provide a framework for conceptualizing the interactions between stressed versus nonstressed individuals at one trophic level with individuals at the next lower and higher trophic levels; and (4) to consider the relationship between setting standards and modeling population-level impacts, and the use of application factors for each.

We diagramed a conceptual framework for considering interactions between stressed individuals at one trophic level with those at the next lower and higher trophic levels, particularly with reference to power plant entrainment as the source of stress. The diagram requires modification when shifting from uncontrolled field studies to controlled laboratory studies designed to test hypotheses and estimate conditional mortality rates associated with a stress.

An equation was derived for the conditional mortality rate due to a stress that incorporates both direct and indirect mortality. Preliminary experiments to test for sublethal effects of heat shock on the feeding of striped bass (Morone saxatilis) larvae suggest that striped bass larvae may be less likely to feed following heat shocks of the type used in these experiments. However, once larvae do start feeding, these experiments suggest that the amount eaten is not substantially influenced by the preceding heat shock.

Although the results from the experiments to test for sublethal effects of heat shock on the feeding of striped bass larvae are preliminary, the methodology of estimating a conditional mortality rate from such results is clear (Van Winkle et al. 1979). Some of the problems of extrapolating from sublethal effects to indirect mortality are also discussed in Van Winkle et al. (1979). In light of these problems, we recommend use of application factors not only in setting standards but also in modeling population-level impacts.

3.3 Biases in Estimates of the Entrainment Mortality Factor

This section is divided into two parts. Section 3.3.1 compares two formulas [Eqs. (3.1-3) and (3.1-4)] in common use for estimating the entrainment mortality factor. A method is presented which examines the accuracy (measured as either relative or absolute deviation of the estimate from the true value) of the formulas, given assumptions about biological and sampling phenomena. Section 3.3.2 elaborates further on the likely direction of biases in estimates of the f-factor, based only on the ORNL formula, resulting from these biological and sampling phenomena.

3.3.1 Quantitative method for estimating the probability of entrainment mortality

Two formulas [Eqs. (3.1-3 and 3.1-4)] have been used for estimating the f-factor. Both formulas contain implicit assumptions about biological and sampling phenomena. Assuming that the sampling method is perfect (no gear avoidance or extrusion) and that all organisms at the intake are collected alive, then both formulas accurately estimate the f-factor. However, if we still assume a perfect sampling method but also assume some proportion of the organisms in the ambient water are dead, then the "OTHER" formula [Eq. (3.1-4)] provides biased (i.e., inaccurate) estimates of the f-factor, while the "ORNL" formula [Eq. (3.1-4)] continues to provide unbiased (i.e., accurate) estimates of the f-factor.

Sampling methods are not perfect. Biological and sampling phenomena that interfere with estimates of the entrainment mortality factor include the following:

(1) some organisms are dead before they ever get near the plant;

(2) some live organisms may avoid the intake area;

(3) some live organisms will avoid the sampling gear;

(4) some captured live organisms will be killed by the gear, and some of these will be extruded (or destroyed);

(5) some dead organisms will be extruded (or destroyed), and extrusion (or destruction) for ambient dead may differ from that for plant-killed; and

(6) gear avoidance, mortality, and extrusion (or destruction) may differ between the intake and the discharge sampling stations.

All of the above phenomena interfere with estimates based on Eq. (3.1-4), while only phenomena (2), (3), (5), and (6) will of necessity interfere with estimates based on Eq. (3.1-3). Phenomenon

(4) interferes with estimates based on Eq. (3.1-3) only if the phenomenon differs between intake and discharge sampling stations.

Three suggestions for improving estimates of entrainment mortality follow. First, to have high confidence in estimates it is necessary to quantify sampling phenomena as much as possible. Second, it is desirable to have comparable sampling conditions at the intake and discharge stations [re Eq. (3.1-3)]. Finally, a technique used to compare the two formulas is also useful for examining the inaccuracy or bias of entrainment mortality estimates arising from biological phenomena and for obtaining improved estimates. This technique (Christensen 1977), consists of the following steps:

(1) specify fixed values for the biological and sampling phenomena (p_1 is determined),

(2) allow the true f-factor to take on values ranging from 0 to 1 (this specifies values of p_2 for each specified value of f),

(3) for each p_2 value, use both formulas [Eqs. (3.1-3) and (3.1-4)] to calculate an estimate of the specified f-factor (incorporating biological and sampling phenomena),

(4) compare each estimate with the specified (or true) f-factor, and

(5) repeat (1) through (4) for a number of hypothetical situations.

Figure 3.3.1-1 is an example of results from this process. Note that the closer the calculated f-factor lies to the 45-degree line, the more accurate the estimate is. If perfect sampling is assumed (no gear avoidance, no extrusion or destruction of initially alive organisms, and the same degree of extrusion or destruction of initially dead organisms and of net mortality at the intake and discharge stations), then the ORNL formula performs accurately and the OTHER formula is biased (Fig. 3.3.1-1). With intake conditions considered similar to discharge conditions and all factors assigned plausible values, neither formula is completely accurate, but the ORNL formula is superior to the OTHER formula over most of the range of true f-factors (Fig. 3.3.1-2). For a plausible case simulating higher velocities at the intake than at the discharge sampling station, assuming use of sampling gear where higher velocity implies higher gear mortality, both formulas perform poorly for low true f-factors, but as the true f-factor increases above 0.2, the ORNL formula rapidly becomes superior to the OTHER formula (Fig. 3.3.1-3). For a plausible case simulating higher velocities at the discharge than at the intake, the OTHER formula performs better for low values of the true f-factor, while the ORNL formula performs better for high values (Fig. 3.3.1-4).

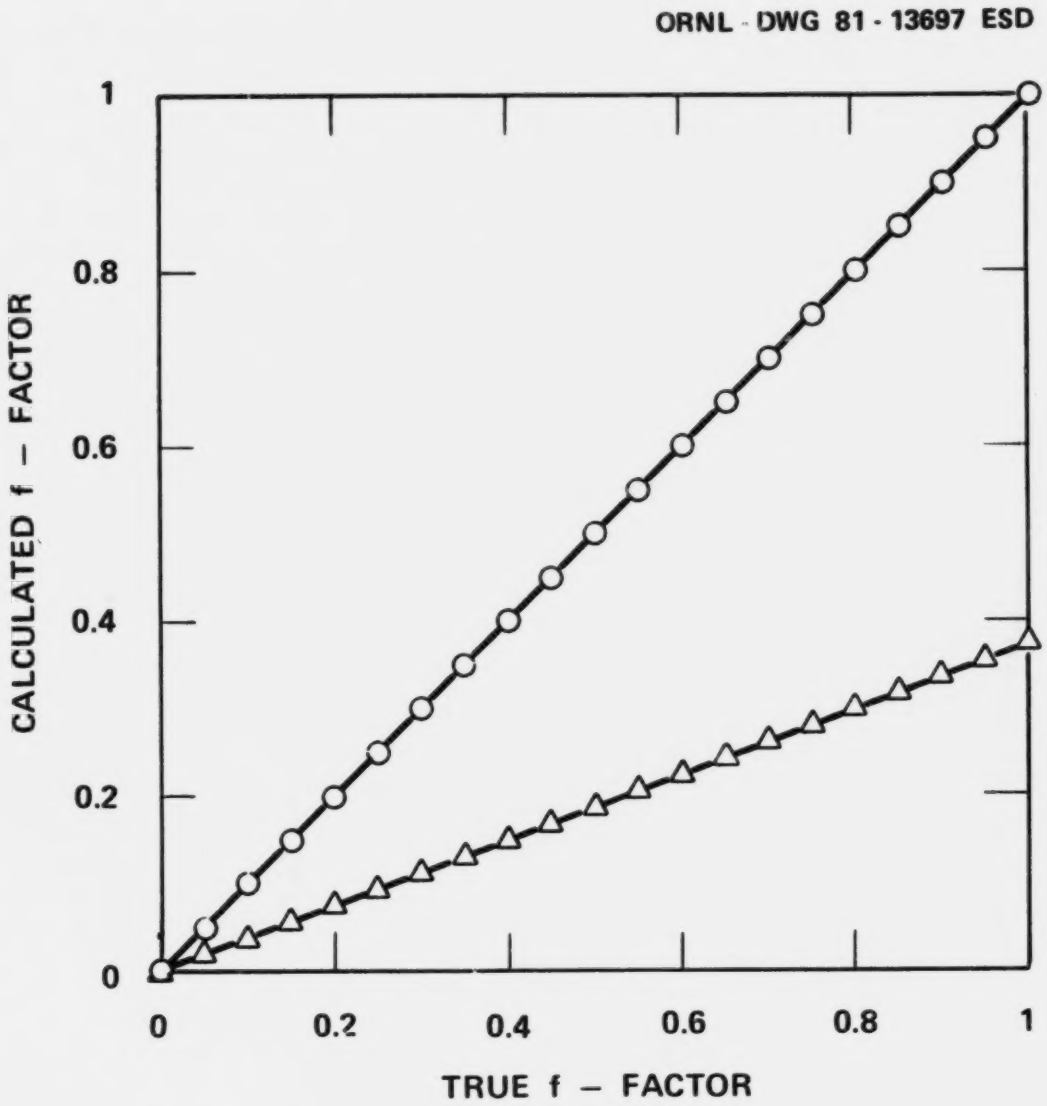


Fig. 3.3.1-1. Comparison of f-factor estimates from the ORNL formula and the OTHER formula, assuming no gear avoidance, no extrusion or destruction of initially alive organisms, and the same degree of extrusion of initially dead oganisms and of gear mortality at intake and discharge sampling stations. Circles represent the ORNL formula and triangles represent the OTHER formula.

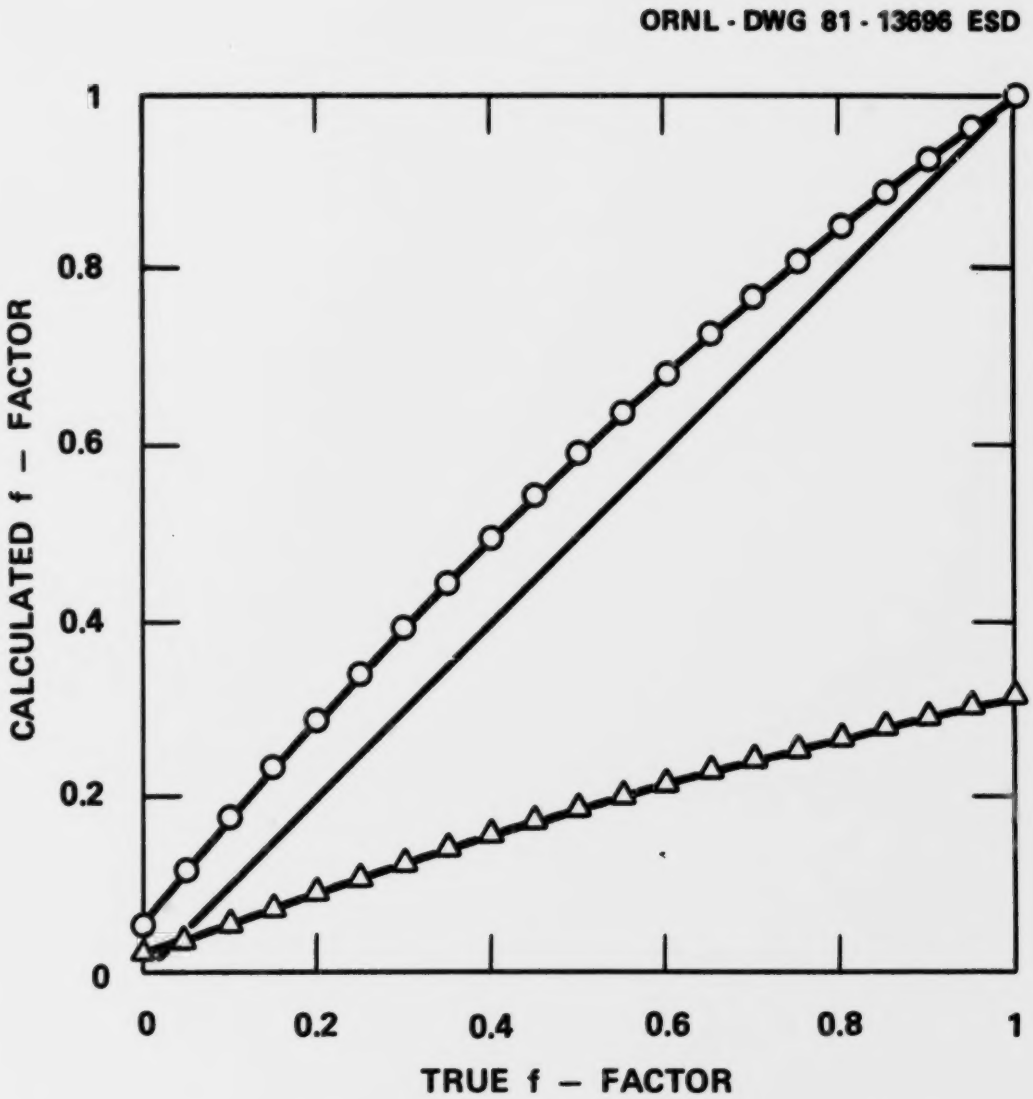


Fig. 3.3.1-2. Comparison of f-factor estimates from the ORNL formula and the OTHER formula, assuming intake conditions similar to discharge conditions and all factors assigned plausible values. Circles represent the ORNL formula and triangles represent the OTHER formula.

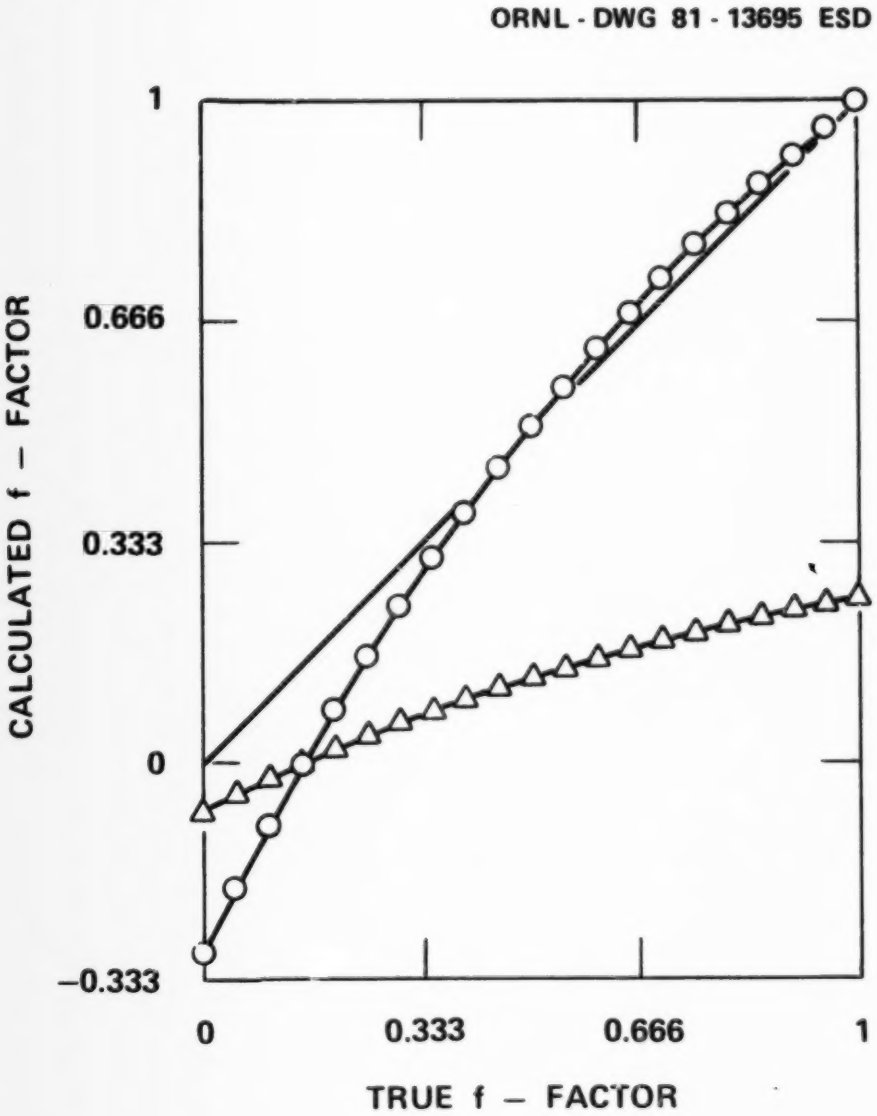


Fig. 3.3.1-3. Comparison of f-factor estimates from the ORNL formula and the OTHER formula, assuming higher velocities at the intake than at the discharge sampling station. Circles represent the ORNL formula and triangles represent the OTHER formula.

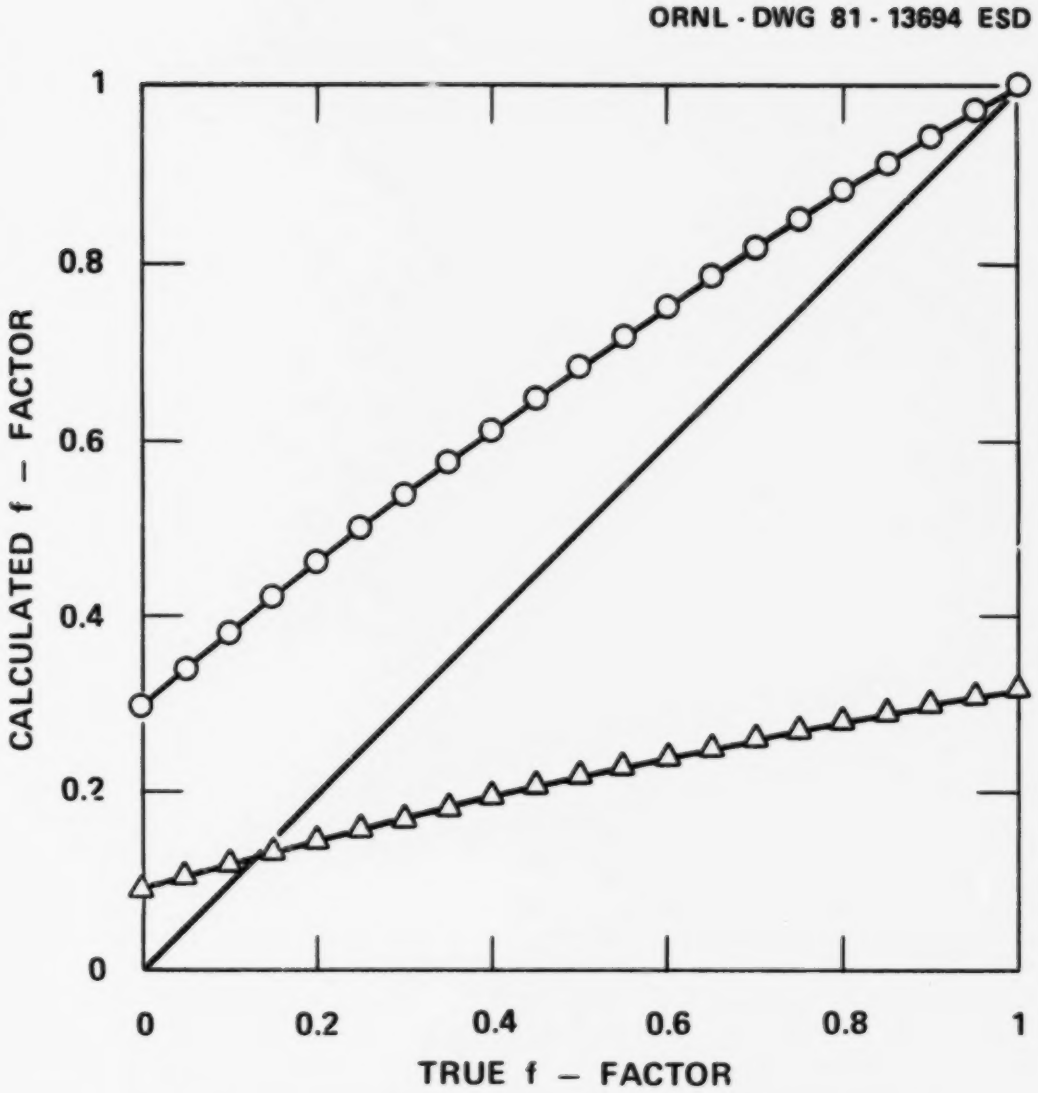


Fig. 3.3.1-4. Comparison of f-factor estimates from the ORNL formula and the OTHER formula, assuming higher velocities at the discharge than at the intake sampling station. Circles represent the ORNL formula and triangles represent the OTHER formula.

Summarizing these results, we find that estimating the f-factor from sampling data is difficult because:

(1) neither formula is completely accurate if gear avoidance or extrusion occurs, or if intake conditions differ from discharge conditions;

(2) the OTHER formula tends to underestimate entrainment mortality, often severely; and

(3) the ORNL formula is fairly accurate when the true f-factor is high, and variable in performance when the true f-factor is low.

3.3.2 Additional biases in estimates of the entrainment mortality

The term bias, when applied to an estimate of a parameter, refers to a systematic tendency to underestimate or overestimate the parameter.When several biases compete, it is important to know, if possible, the direction of bjas due to each source and the likely direction of net bias. It is also desirable to develop a feel for the magnitudes of these biases.

In this section we discuss several examples of possible underlying conditions that could cause biases to occur in estimates of the f-factor. These biases stem from simplifying assumptions made in the development of the f-factor equations (Vaughan 1979, Appendix C.1, Boreman et al. 1982, Appendix C.1). We suggest the likely direction of each bias.

We begin by considering a simple example to illustrate how such biases can arise from sampling procedures. Let us suppose that the sampling process at the discharge station kills all of the live organisms collected. This supposition is independent of the fraction actually killed as a result of plant passage. Employing Eq. (3.1-3), we note that the fraction of organisms alive in the discharge samples (p_2) is:

$$p_2 = 0.0 \quad , \tag{3.3.2-1}$$

so that the estimate of the initial f-factor (f) is given by

$$f = 1 - \frac{p_2}{p_1} = 1 - \frac{0}{p_1} = 1.0 \quad , \tag{3.3.2-2}$$

irrespective of p_2. Thus, the estimate of f equals 1.0 whether the true f-factor (f), is 0.0, 0.5, 1.0, or any other value between 0 and 1. Only if the true value of the f-factor is equal to 1 is this

estimate unbiased. However, if any organism survives passage through the power plant, then the true f-factor is less than 1, and our estimate of complete mortality will overestimate the true f-factor.

However, we need not assume such an extreme situation for an estimate of the f-factor to be biased. If the sampling-induced mortality at the discharge station is not complete, but is merely greater at the discharge than at the intake sampling station, then the estimate of the f-factor from Eq. (3.1-3) will overestimate the true f-factor (other conditions being equal), except when the true f-factor is 1.0. Synergistic effects between plant passage stresses and discharge sampling stresses might result in the occurrence of this situation. On the other hand, if the sampling-induced mortality is greater at the intake than at the discharge sampling station (e.g., greater cooling water velocity at the intake as compared to the discharge sampling station when collecting data using nets), then the estimate of the f-factor will always underestimate the true f-factor (other conditions being equal), except when the true f-factor is 0.0.

Differential catchability of live organisms at the intake and discharge sampling stations (all else being equal) also results in a bias. For example, if a live organism is more capable of avoiding the sampling gear at the intake than at the discharge sampling station, the resultant estimated f-factor will underestimate the true f-factor.

Two more conditions can cause an estimate of the f-factor to be biased. Differential catchability in the discharge of plant-survivors as compared to plant-killed organisms will result in a biased estimate of the f-factor. In particular, greater catchability of plant-killed organisms will result in an overestimate of the true f-factor (all else being equal). This phenomenon might occur as a result of avoidance behavior by live organisms. On the other hand, if plant-killed organisms are less susceptible to capture in the discharge than are live organisms, then the estimated f-factor will underestimate the true f-factor (all else being equal). Organisms surviving plant effects may have their avoidance capabilities impaired and plant-killed organisms might settle or float to the surface. In this situation live organisms may be more susceptible to capture by the discharge sampling gear than plant-killed organisms, thus resulting in an underestimate of the true f-factor.

Assuming that dead organisms are entrained (which might result from natural causes or from the recirculation of cooling water containing some organisms previously killed by the plant), differential catchability at the intake of dead as compared to live organisms will result in a biased f-factor (all other conditions being equal). In particular, if live organisms in the river are capable of avoiding the intake sampling gear and thus are under-represented in the intake sample but dead organisms in the river are representatively sampled, the estimate of the f-factor will underestimate the true f-factor (all other conditions being equal). On the other hand, if for some reason

dead organisms from the river are more under-represented in the intake sampling gear than the live organisms but proportionately represented in the discharge sample, then the estimate of the f-factor will overestimate the true f-factor (all other conditions being equal).

This set of examples is not exhaustive. However, it does indicate some of the potential sources of bias present in almost any sampling program designed to estimate the f-factor. A recent paper by Boreman and Goodyear (1981) covers this topic in greater detail.

3.4 Detectability and Precision of Estimates of the Entrainment Mortality Factor

The impact of power plants on fish populations is an important area of environmental concern. The ability to detect and develop precise and accurate estimates of entrainment mortality is important in projecting power plant impacts on future fish population levels. Recent work indicates that these mortalities may be considerably less than 100% for the early life stages of some fish species (Barnthouse et al. 1977, Cannon et al. 1977, Ginn et al. 1977, Cada et al. 1981, and Jinks et al. 1981). Ignoring potential entrainment survival can lead to an overestimate of power plant impact on fish populations.

Whenever a researcher obtains an estimate of a parameter, it is important to have knowledge about the precision of that estimate. The precision of an estimate becomes even more important when that estimated parameter is input to a model used for predictive purposes, because variability in model input parameters can magnify the variability of model output (Gardner et al. 1980, O'Neill 1973, and O'Neill and Gardner 1979). Furthermore, the greater the precision with which we can estimate a parameter, the greater the chance that we will detect the underlying parameter as being different from some specified value when the underlying parameter does, in fact, deviate. The failure to detect this difference when it exists refers to the type II (β) error. The power of a statistical test ($1 - \beta$) is the probability of correctly rejecting the null hypothesis of no difference. In most statistical tests one begins by setting the type I (α) error, the probability of finding an apparent difference between the underlying parameter estimated and the hypothesized value of the parameter when the observed difference can be explained purely by random error. Once the type I error is set, sample size often will determine the level of the type II error (and the power of the statistical test).

For estimates of the f-factor the hypothesis that no difference exists between the intake (p_1) and discharge (p_2) probabilities implies that

$$H_0: \quad f = 0 \quad . \tag{3.4-1}$$

If p_1 is greater than p_2, then f is greater than zero (but less than or equal to one). Observing p_1 less than p_2 is assumed to occur only from random sampling error, and one would set f to zero.

The statistical test used to evaluate the null hypothesis [Eq. (3.4-1)] uses the test statistic (Fleiss 1973):

$$Z = \hat{f}/s.e.(\hat{f}) \quad , \tag{3.4-2}$$

where

$$s.e.(f) = \frac{1}{\hat{p}_1}\sqrt{\frac{\hat{p}_2(1-\hat{p}_2)}{n_2} + (1-\hat{f})^2 \frac{\hat{p}_1(1-\hat{p}_1)}{n_1}} \quad , \tag{3.4-3}$$

and n_1 and n_2 are the number of organisms collected at the intake and discharge sampling stations, respectively. A common sample size, n, is assumed for the intake and discharge samples. When the calculated Z exceeds a tabled value of the standard normal deviate (as a function of the type I error), then it is concluded that f is greater than zero.

Three desirable results from an entrainment mortality sampling program include: (1) low-minimum detectable entrainment mortality (or the ability to detect small estimated entrainment mortalities as significantly greater than zero), (2) high statistical power (i.e., a high probability of rejecting the null hypothesis of no entrainment mortality when this null hypothesis is false), and (3) narrow confidence intervals (or more precise estimates). These desirable results are enhanced by (1) increased sample sizes at the intake and/or discharge sampling stations, and (2) increased fraction alive in the intake (or control) sample.

For a particular fraction alive in the intake sample (p_1), the intake (and discharge) sample size (n) necessary to attain a fixed level of each of the three desirable results can be determined. As an example, the more "power" one needs, the larger will be the required sample size, especially for small fractions alive in the intake sample. This principle is highlighted in Fig. 3.4-1, assuming an underlying entrainment mortality (f_0) of 0.5. One can readily see that there is a considerable reduction in the required sample size for a fixed power by improving sampling gear to increase the fraction alive in the intake sample from 0.1 to 0.5. However, a far smaller reduction in the required sample size will occur when one increases the fraction alive in the intake sample from 0.5 to 0.9. Furthermore, the power curve for a fraction alive in the intake sample of 0.1 is much steeper than the power curve for a fraction alive in the intake sample of 0.5. Thus, a

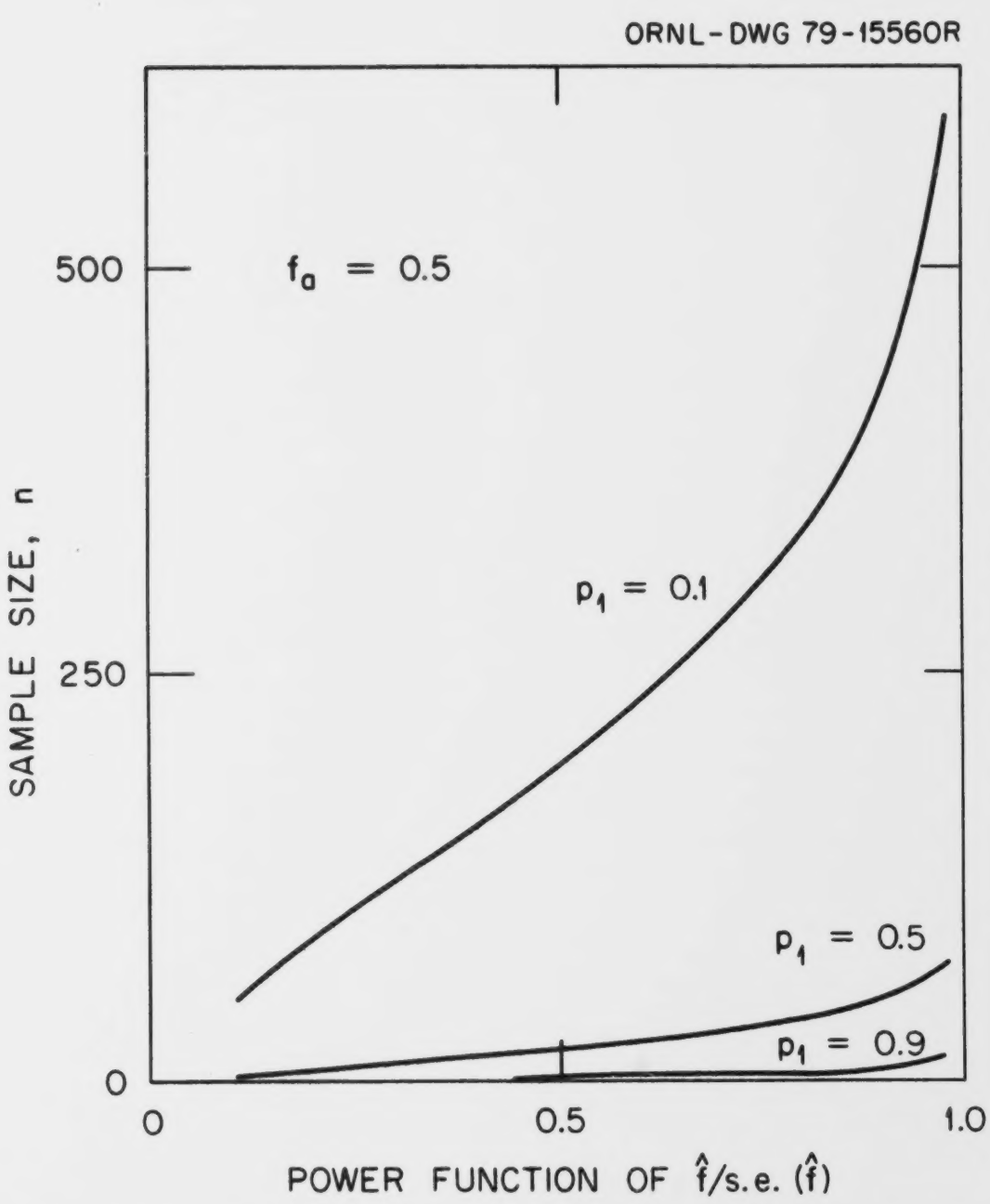


Fig. 3.4-1. Sample size required as a function of statistical power for three levels of the fraction alive in the intake sample (p_1), assuming an underlying entrainment mortality (f_0) of 0.5.

small increase in the sample size when the fraction alive in the intake sample is 0.5 will improve the power of the statistical test considerably more than the same increase when the fraction alive in the intake sample is 0.1.

This investigation which is discussed is more detail in Vaughan and Kumar (1981) points out the need for improving the sampling gear used in obtaining live organisms from the intake and discharge sampling stations. The need for increased numbers of organisms collected (alive and dead) is also highlighted. The number of organisms collected can be increased by increasing the volume of water filtered (or pumped) or by increasing sampling effort during periods of maximum concentration of the organism. These results can lead to designing more useful and efficient monitoring programs for determining power plant impacts.

3.5 Effects of Variation on Estimates of the Entrainment Mortality Factor

Biological phenomena such as gear avoidance, gear-induced mortality, extrusion through nets, and the presence of dead organisms in ambient water introduce error into estimates of the f-factor. An additional difficulty is that, because of small sample sizes, it is usually necessary to combine data from many samples, taken under different conditions, before estimating f. As a result, Christensen and DeAngelis (1982) developed a computer model, ENTRAN, to probe the performance of estimators of the f-factor. The utility of this model lies in its ability to simulate not only the entrainment mortality sampling process but also the estimation of the f-factor by either Eq. (3.1-3) or Eq. (3.1-4). ENTRAN is in essence a stochastic simulation model based on a "neutral modeling" approach (Caswell 1976). The entrainment process is repeatedly simulated, with key variables allowed to vary randomly. In each repetition the true value of the entrainment mortality factor (f-factor) is selected, and it is compared with estimates of this factor obtained from the alternate formulas discussed above. The reliability of each formula can then be evaluated by comparing the estimates of the f-factor with the corresponding true values. Ideally, a formula would always estimate the true f-factor without error. In real-world cases, however, this is impossible. ENTRAN enables an examination of the magnitude and variance of error as a function of variability introduced by various sampling phenomena.

A number of runs were made to verify the program and to illustrate ways in which it can be used. In simulations where the mean parameter values met the assumptions of the ORNL formula, the random variation alone caused biased estimates. The ORNL formula overestimated mortality when mortality was high and underestimated mortality when mortality was low. The "averaging" due to combining samples was somewhat effective in reducing the variance of this bias, but it had little effect on the magnitude of the bias. The same results were

obtained for a more realistic case where the assumptions of the ORNL formula were not met. In some instances, the OTHER formula was a better estimator of the f-factor than was the ORNL formula.

The program is intended primarily for application to a specific situation, because experience has shown that the factors in the model will likely vary widely between different types of sampling gear (O'Connor and Schaffer 1977, McGroddy and Wyman 1977) and also between species (Vaughan 1979, Ecological Analysts 1977b). We intend for the program to be viewed as flexible, in that the biological assumptions built into the present version may not best describe, or even adequately describe, a particular sampling situation or species. When suitably modified to reflect what is known or suspected about the biology of the sampling situation, the designer of the sampling program can make good use of ENTRAN to address needs in several areas. The exercise of providing ranges of values for the parameters will likely indicate to the biologist where uncertainty about these parameters is greatest. In conjunction with this exercise, sensitivity analysis of the model will indicate profitable areas for further research which will be helpful in improving the reliability of estimates.

ENTRAN can also aid in designing the sampling program and in interpreting the results. The program can be used to study the relative effects of estimating the f-factor from many, small samples versus fewer, larger samples, and it can indicate how reliability is influenced by small sample sizes, given uncertainty in the parameters. It can also be used in a general way to evaluate the reliability of f-factor estimates calculated from sample data. Depending on the degree of confidence in the input parameters, the program will be useful in evaluating the bias of estimates and in indicating how estimates calculated with a particular formula can best be "corrected."

4. BIOLOGICAL COMPENSATION AND STOCK-RECRUITMENT THEORY

4.1 Introduction

All of the work described thus far relates to obtaining conditional mortality rates for entrainment and/or impingement impacts. These rates estimate the fraction of the initial population that would be killed by entrainment or impingement during a specified time period in the absence of other sources of mortality. Such conditional mortality rates are analogous to the conditional fishing mortality rate as defined by Ricker (1975). The conditional entrainment or impingement mortality rate is equivalent to the fractional reduction in year-class strength following the time period of entrainment or impingement if the other sources of mortality are density-independent. This situation exists regardless of the magnitude of the mortality due to other sources.

A conditional mortality rate (e.g., for entrainment or impingement impact), or a combined conditional mortality rate for both kinds of impact, should not be considered the sole possible measure of entrainment impact on a fish population. Density-dependent natural mortality may act to reduce or magnify the reduction in year-class strength caused by entrainment. Such density-dependent mechanisms were introduced as an issue in the Indian Point controversy in 1972 (Lawler 1972a and 1972b). In these early LMS models, Quirk, Lawler and Matusky Engineers, consultants to Consolidated Edison, Inc. (Con Ed), used a "compensatory" function in the form of a cubic equation which varied the instantaneous mortality rates of young-of-the-year fish as a function of population density. Thus, decreases in population density due to entrainment and impingement mortality were largely compensated for in the model by increased survival of the remaining fish. In principle, this introduction of density dependence in natural mortality rates is in accord with ecological theory (e.g., Holling 1973), although the likely magnitudes (and sometimes the direction) of density-dependent responses are generally unknown. Con Ed's position, based on results from one of the LMS models, was that the impacts of power-plant operation with once-through cooling were small and acceptable. Scientists at Oak Ridge National Laboratory (ORNL), however, had considerable misgivings about this function and performed a critique of it (Section 4.2).

Texas Instruments, Inc., another consultant to Con Ed, proposed a different approach, based on a consideration of stock and recruitment concepts, in a 1975 report (Texas Instruments 1975a).
Stock-recruitment theory itself was developed years ago by fisheries scientists (Ricker 1954, Beverton and Holt 1957) in an attempt to understand fish population dynamics, especially in the context of fishing yields. Anticipating that the controversy about biological compensation would shift into the stock-recruitment arena, ORNL began work on the extension of stock-recruitment theory to cases involving

power plant impacts on young-of-the-year fish rather than exploitation of adult and sub-adult stocks. The primary outcome of this work was a model which, besides treating power plant impacts, also combined the classical Ricker and Beverton-Holt stock-recruitment models into a single unified model (Section 4.3).

As anticipated, Con Ed and two other utilities relied on stock-recruitment theory to quantify compensation in several fish populations in a consolidated adjudicatory hearing before the U.S. Environmental Protection Agency (EPA). The question of whether the theory was applicable to the Hudson River, and if so whether their methods were reliable, was perhaps the most controversial technical issue in the hearings. Partially under funding from this project, a method of evaluating the validity of the utilities' use of stock-recruitment theory was developed (Section 4.4). Application of this method demonstrated that the utilities' attempt to utilize stock-recruitment approaches to quantify compensation was a failure.

A final aspect of this work concerned the application of curve-fitting procedures of environmental variables and stock size on recruitment for three fish populations. Three regression approaches were tried. No single approach was found to be consistently superior in explaining recruitment variation for all three fish stocks (Section 4.5).

4.2 Critique of the LMS Compensation Function

In 1972, Lawler, Matusky & Skelly Engineers (LMS), under contract to Consolidated Edison Company of New York, first introduced a compensation function as a key component of their striped bass models (Lawler 1972a, 1972b). In light of our misgivings concerning this compensation function, we performed a critique and sensitivity analysis (Van Winkle et al. 1976).

The description and justification for the compensation function developed and used by LMS (under contract to Consolidated Edison Company of New York) in their Hudson River striped bass models was presented. A sensitivity analysis of this compensation function was reported, based on computer runs with a modified version of the LMS completely mixed (spatially homogeneous) model. Two types of sensitivity analysis were performed: (1) a parametric study involving at least five levels for each of the three parameters in the compensation function, and (2) a study of the form of the compensation function itself, involving comparison of the LMS function with functions having no compensation at standing crops either less than or greater than the equilibrium standing crops. For the range of parameter values used in this study, estimates of percent reduction are least sensitive to changes in the equilibrium standing crop (YS), and most sensitive to changes in the minimum mortality rate coefficient (KXO). Eliminating compensation at standing crops either less than or

greater than the equilibrium standing crops results in higher estimates of percent reduction. For all values of KXO and for values of YS and the equilibrium mortality rate coefficient (KX) at and above the baseline values, eliminating compensation at standing crops less than the equilibrium standing crops results in a greater increase in percent reduction than eliminating compensation at standing crops greater than the equilibrium standing crops.

The conceptual basis for the LMS compensation function was criticized, particularly the lack of a sound biological basis for the left limb of the function. An alternative functional form was presented by Van Winkle et al. (1976). The lack of a relationship between any of the three parameters in the LMS compensation function and measurable biological phenomena was also criticized.

Together, the critique and sensitivity analysis of the compensation function used in the LMS Hudson River striped bass models highlight the need for caution in relying on these models to reach a reasoned decision on the potential impact of the Hudson River power plants on the striped bass population.

This LMS compensation function was heavily relied on by the utilities from 1972 through 1976 (Lawler 1974, LMS 1975). By 1977 their approach to the handling of compensation in their striped bass simulation model had changed (McFadden 1977), in part because of the report by ORNL critiquing their compensation function.

4.3 Development of a Stock-Progeny Model for Assessing Power Plant Effects on Fish Populations

Figure 4.3-1 shows two forms of stock-recruitment curves which have been widely used in analyzing fish populations. In general, stock-recruitment theory and the models which underlie such curves were used to analyze the effects of fishing. Because fishing mortality acts on fish older than those generally killed by power plants, there was a need to extend stock-recruitment theory via the development of a new model. The purposes of this task were: (1) to develop a simple model, based on broad biological principles and capable of producing stock-recruitment relationships similar to those in Fig. 4.3-1 and (2) to examine the potential impact of power plant cropping of young-of-the-year fish for a range of stock-progeny relationships. The phrase "stock-progeny" rather than "stock- recruitment" is used because reproduction is measured in units of stock value, rather than as recruitment in the sense of Ricker (1975) (i.e., recruitment to a fishery). If different indices were used in the same model, it would be fully appropriate to refer to it as a "stock- recruitment" model.

In general, stock-recruitment theory is particularly applicable to the simulation modeling of fish populations if the probability of survival of an egg to a yearling or to an adult stage is a decreasing

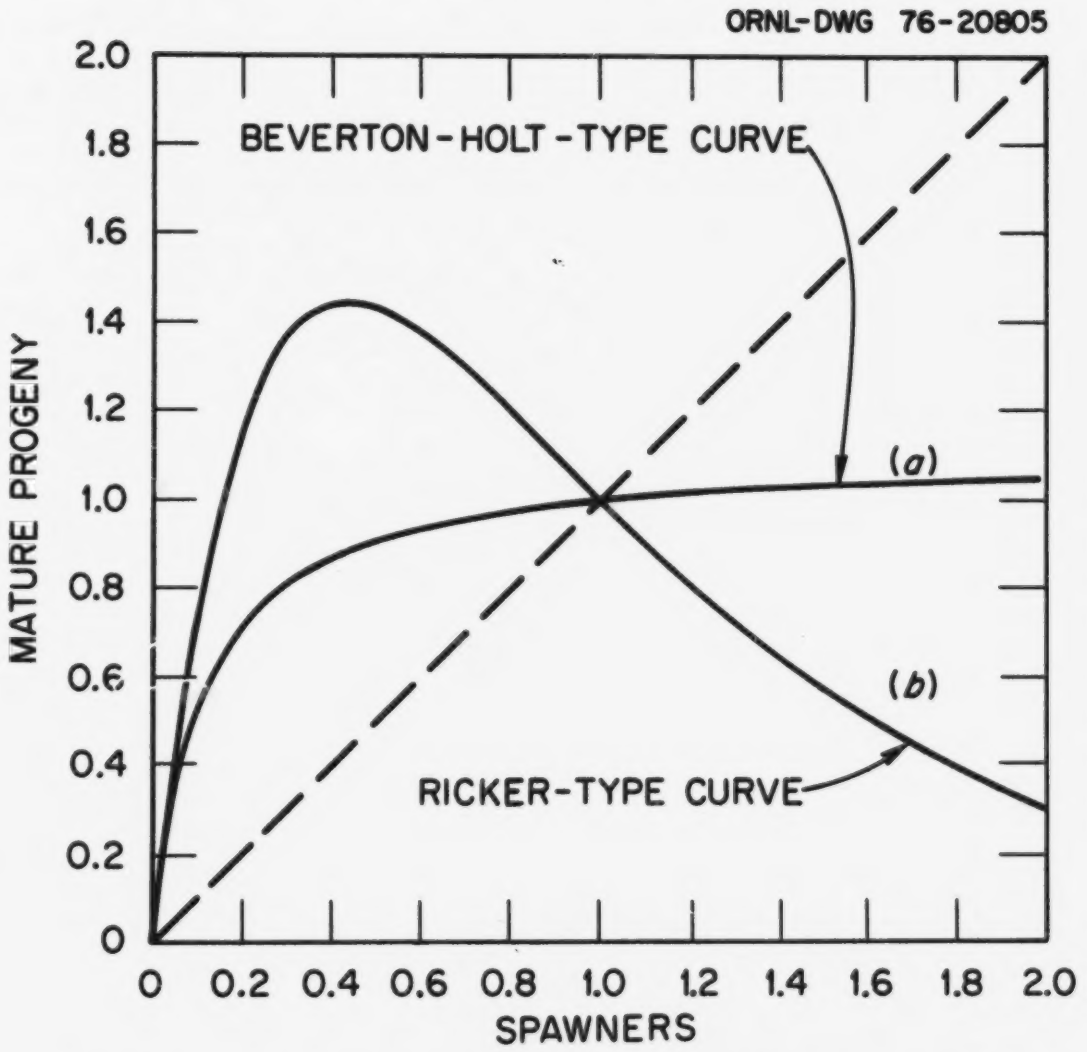


Fig. 4.3-1. Two forms of classical stock-recruitment (reproduction) curves: (a) the Beverton-Holt-type curve and (b) the Ricker-type curve. The intersection of such a curve with the (dashed) 45° line is the equilibrium point. (Source: Christensen et al. 1977).

function of stock size, that is, if compensation is operating in the population. The implementation of a specific compensatory function in an impact model implies a certain type of stock-recruitment relationship in the modeled population. Conversely, a particular causal stock-recruitment relationship restricts plausible compensatory mechanisms in an impact model, if the model is to be capable of reproducing that relationship.

A multi-age-class model, based on simple but general biological principles, was developed to assess the impact of power plants on fish populations (Christensen et al. 1977). This model combines the classical Ricker (1954) and Beverton and Holt (1957) stock-recruitment models (DeAngelis and Christensen 1979), but it is oriented to analyzing the effects of mortality on young-of-the-year fish rather than on recruits to the fishery.

The model was parameterized to produce a variety of stock-progeny relationships, assuming that the stock is always at stable age distribution. The predicted response of the fish stock to power plant cropping of young-of-the-year fish was investigated for each of these stock-progeny relationships.

The application of the model was intentionally "results oriented" in the sense that the model was "forced" to assume a variety of arbitrary stock-progeny relationships. For each set of parameters that produced a desired form of relationship, the impact factor was evaluated at one or more levels of impact. While the reasons for many of the results are not intuitively obvious, some interesting and relevant generalizations emerged:

(1) The impact factor is a measure of the sensitivity (or vulnerability) of the stock to power plant cropping. In general, the impact factor is positively related to the slope at the equilibrium point (i.e., increases as the slope becomes more positive) and to a lesser extent is negatively related to the slope at the origin. Thus, the greater the deviation of the Ricker-type or Beverton-Holt-type stock-progeny relationship from the 45° reference line, the less sensitive the stock is to power plant cropping. The timing of cropping in relationship to compensation is, however, quite important in determining the impact factor, when the Beverton-Holt mechanism is operative.

(2) For a wide range of stock-progeny relationships, power plant cropping in our model always acts to decrease the equilibrium stock size from its unimpacted value. This finding is investigated analytically in DeAngelis et al. (1977).

(3) The numbers, fecundities, and death rates of the older age classes are not particularly important in determining the sensitivity to power plant cropping if the stock-progeny relationship is known.

Taken together, these results indicate that if a casual relationship can be established between stock size and production of progeny in a population of interest, some inferences may be possible about the eventual effect of increased mortality during the young-of-the-year period. The empirical approximation for the impact factor [Eq. 15 in Christensen et al. (1977)] will indicate the magnitude of the eventual effect of modest impacts if the slope at equilibrium is known and the model describes reasonably well the population and the forces acting on it. In addition, the critical impact [Eq. 17 in Christensen et al. (1977)] indicates a level of impact which, if approached, would entail a substantial risk to the population in the long term.

The difficulty in applying the results should, however, not be underestimated. These results assume stable age distribution (SAD), whereas the information needed to infer the SAD stock-progeny relationship will necessarily come from populations that are varying in size. Such populations will almost surely not have a stable age distribution. It would be necessary to have much more detailed information than is generally available, collected over a long period of time, to establish the actual relationship between "stock size" and the "stock value of progeny."

Practical application of this model to specific cases will require an approach based on dynamic simulations. Allowing parameters in the model to vary randomly can result in different kinds of periodic behavior, depending on the mean values of the parameters (DeAngelis et al. 1977). If the available data consist of a time-series of catch data which represents sub-samples of only certain ages of the stock and from which specific age-structure information cannot be obtained, a catch index can be constructed in the model. Determination of possible values for the unknown parameters in the model can be based on the ability of the simulated catch index to reproduce the observed catch data. It is important to note that age-specific fecundity values and death rates, which are relatively unimportant in determining the sensitivity to power plant cropping when the stock-progeny relationship is known, may be a quite important component in the dynamic simulations needed to establish the stock-progeny relationship. In addition, more than one stock-progeny relationship (or none at all) may be consistent with the available information, and the prediction of impact may be indeterminate. Nonetheless, given the lack of direct data to serve as a guide to parameterizing detailed young-of-the-year compensatory functions, we believe that further work with this and similar models will provide additional insights into the question of the potential effects of power plants on fish stocks.

4.4 Stock-Recruitment Model Validation

The question of biological compensation was a key issue in the EPA adjudicatory hearing, with the application of stock-recruitment theory

one of the main points of contention. The utilities claimed that a curve-fitting exercise utilizing a stock-recruitment model could be used to quantify compensatory reserve. EPA and its consultants were highly dubious of this claim. ORNL, in cooperation with C. P. Goodyear of the U.S. Fish and Wildlife Service's National Power Plant Team, devised and implemented a computer simulation approach to test the validity of the utilities' approach (Christensen et al. 1979, Christensen et al. 1982, and Christensen et al., in preparation).

The utilities' curve-fitting exercise relied on least-squares regression. In this instance, the Ricker stock-recruitment model (Ricker 1954, 1975), as modified for a multiple-age spawning stock, was assumed to describe the processes which regulate the population. In its basic form, the Ricker model is:

$$R = \text{alpha} \times P \times \exp(-\text{beta} \times P) \quad , \qquad (4.4\text{-}1)$$

where R denotes recruits, P denotes parents or the fish stock that produced the recruits, and alpha and beta are unknown parameters in the model which describe the relationship between the size of the recruit population and the size of the parent population. Based on estimates of the parameter alpha in the Ricker model, the utilities converted estimates of annual entrainment and impingement impacts of the Hudson River power plants on young-of-the-year striped bass to estimates of long-term reduction in the equilibrium population size of adult striped bass. The value of alpha they chose to use is 4. Had they used a lower value, predicted power plant impacts would have been substantially higher. The utilities abstracted this value of 4 for alpha from the results of the curve-fitting exercise, which they conducted as follows.

First, they assumed that the Ricker model applies to the Hudson River striped bass population (i.e., they assumed that the relevant biological characteristics of the Hudson River striped bass population are adequately described by the model). Second, they subjected a 26-year time series of "catch-per-unit-effort" (CPUE) numbers (obtained by manipulation of various historical statistics) to further manipulation in a number of alternative ways to yield values which they treated as indices of "stock" (parents) and "recruits" (offspring of the parents). Third, they applied linear regression to "fit" a transformed version of the model to the various sets of stock-recruit data obtained from the indices. From this procedure, they obtained estimates of the value of alpha.

This procedure is vulnerable to challenge on many grounds. This portion of the task addresses a single fundamental question: if the Ricker model really did apply to the Hudson River striped bass population, could the utilities' estimates of the parameter alpha, obtained from the curve-fitting exercise, be considered to be reliable?

Our investigation is a "validation analysis" in that it is intended to assess the validity of the utilities' approach to estimating the parameter alpha in the Ricker model. The technique that we use is an adaptation of one proposed some eighteen years ago by Dr. James T. McFadden (McFadden 1963), one of the utilities' primary biological consultants during the hearings. The technique involves specifying, for the purpose of the analysis, a particular numerical value for the parameter in question (in this case, alpha). Second, a model is used to generate simulated time series data. These simulated data are designed to match the salient characteristics of the Hudson River data used as a CPUE index by the utilities. Third, these simulated data are manipulated in the same ways the utilities manipulated the "real" data. Next, the curve-fitting procedure is applied to the simulated data to produce estimates of the parameter alpha, which of course is known for the model. If the estimates are the same as the specified value, or very close, it can be concluded that the curve-fitting technique gave reliable estimates in the case of that particular model and that particular specified value of alpha. If this entire procedure is repeated, specifying each time a different value of alpha, it can be determined whether, for the particular conditions in the model used to generate the data, the curve-fitting exercise gives reliable results for all actual (i.e., specified) values of alpha, only for some values, or for none at all. The final step is to repeat the entire procedure, perhaps several times, with different conditions in the model. In this way, the reliability of the curve-fitting exercise for a variety of possible conditions can be assessed.

By way of illustrating this technique, a procedure termed the "proxy approach" is addressed. The "proxy approach" was advanced by the utilities' witnesses during cross-examination as a justification for their preference for the alpha estimates obtained using a "five-year lag" to manipulate the data. A "five-year lag" as used in this sense means that when a CPUE index from some year (t) is used as an index of stock, the CPUE index for year (t + 5), five years later, is used as the corresponding index of recruits. The more conventional approach, known as the "generation time" approach, suggests that a longer lag, related to the generation time of the population, would be more appropriate. For a multiple-age spawning population, the generation time is approximately the age by which a given "average" female fish has spawned one-half of her total lifetime contribution of eggs. The methodology developed is suitable for investigation of this controversy. The methodology is applied to a test case that one of the utilities' consultants proposed during cross-examination as an example of a situation where the "proxy approach" should be appropriate. Figure 4.4-1 presents some typical results, showing the generally substantial deviations between the source models used to generate artificial catch statistics and the fitted models obtained from these statistics using the utilities' fitting procedures. All of the results support the generation time approach in preference to the proxy approach although, as might be expected, neither works very well.

ORNL DWG 82 7390 ESD

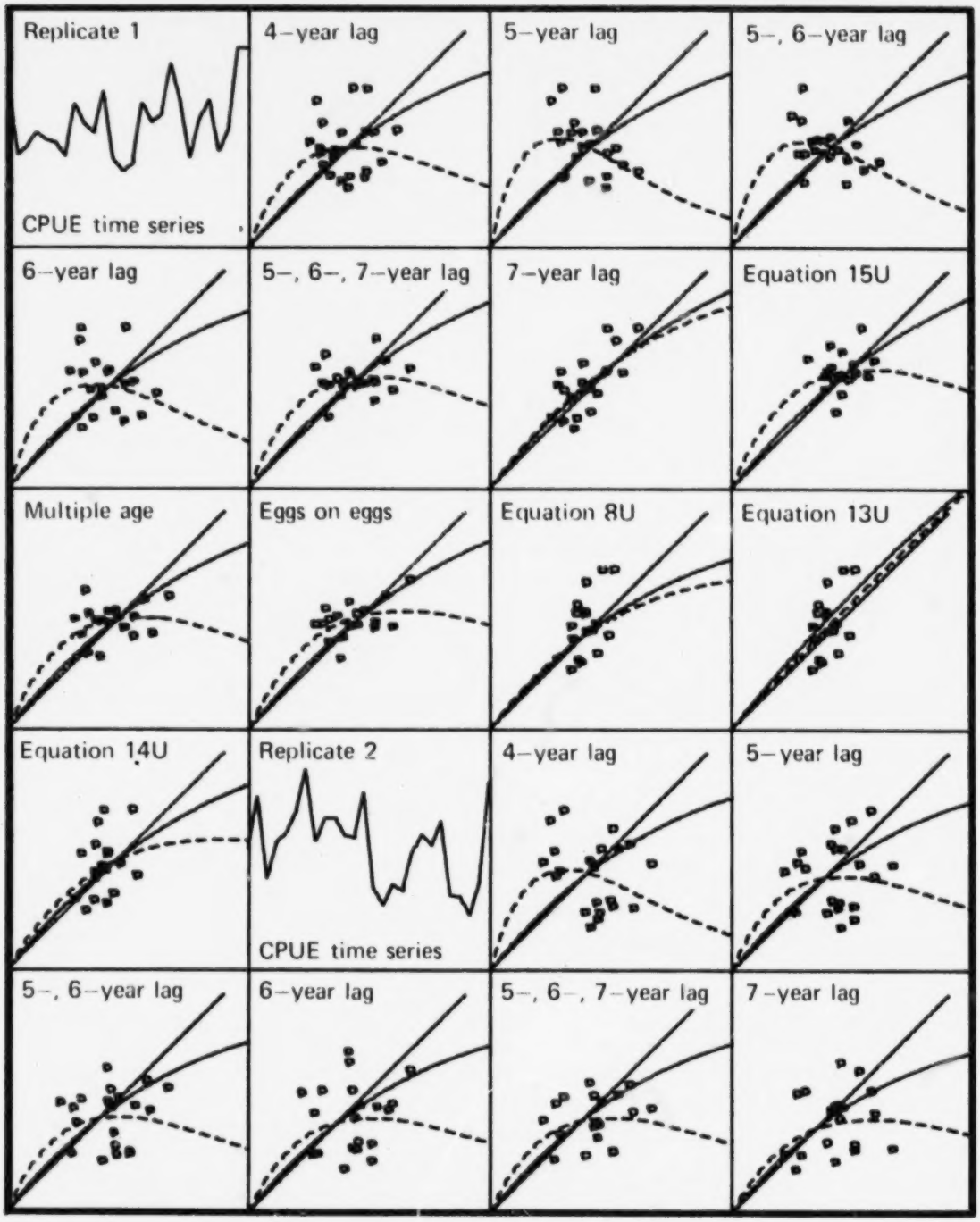


Fig. 4.4-1. Results from Replicate 1 and part of Replicate 2 for Case 102, Run 933 - the proxy test case with alpha of 1.25 and random variation in young-of-the-year mortality. Solid Ricker curves are the source model, dashed curves are the fitted model. (Source: Christensen et al. 1979).

MICROFILMED FROM BEST AVAILABLE COPY

Next, this methodology is applied to the curve-fitting exercise involving the fitting of the Ricker model to the Hudson River 1950-1975 CPUE time series for striped bass. This subset of the utilities' curve-fitting exercise was chosen because it represented the latest of the utilities' efforts and the one on which they placed greatest emphasis. Included in the analysis are some other approaches to manipulating the data which the utilities still maintain are valid concepts, even though they have deleted the results from the original application of these approaches and have not replaced them or applied them to the updated data set. Another procedure proposed more recently by the utilities, termed here the technique of "prior estimation of beta," is also treated as a parallel to the curve-fitting exercise. The unequivocal conclusion reached from these studies is that none of these techniques used by the utilities produces reliable estimates of alpha. For most values of alpha in the model, the estimates are substantially biased. In addition, the statistical test used to determine the significance of the term "beta" in the Ricker model, which accounts for biological compensation, yields spurious results. This test usually indicates that beta is greater than zero, implying compensation, even when beta is in fact zero.

The failure of the utilities' curve-fitting exercise to produce reliable estimates of alpha is not surprising, in view of the transformation of the model which is required for linear regression, the amount of variation in the data, and the conceptual lack of suitability of any of the techniques for manipulating the basic data to provide accurate indices of stock and recruits because of the biological complexities introduced by multiple-age spawning. Taking the value of Ricker's alpha to be a measure of compensatory capacity, as the utilities would have us do, the validation procedure shows that the utilities' curve-fitting exercise provides virtually no useful information about the short-term or long-term consequences of power plant impact on the striped bass population in the Hudson River.

We recommend that the utilities' projections of long-term impact, which stem from their fitting of the Ricker model to striped bass data, be ignored. Further, we recommend application of this validation technique for any stock-recruitment curve-fitting exercise for which there is reasonable question about the appropriateness of the data or methodology and on which important decisions depend.

4.5 Regression Analyses of Stock-Recruitment Relationships in Three Fish Populations

Regression analyses were performed (Yoshiyama et al. 1981) on data for striped bass in California, Atlantic menhaden on the U.S. Atlantic coast, and American shad in the Connecticut River. We examined the statistical dependence of recruitment level upon stock size and environmental variables using three regression approaches: (a) linear models with single- and multiple-predictor variables; (b) Ricker and Beverton-Holt stock-recruitment models, followed (where appropriate) by

linear regression of residuals on environmental variables; and (c) Ricker and Beverton-Holt stock-recruitment models modified to include an environmental variable. This comparison of three regression approaches for three fish stocks may provide a basis for future assessments of the effects of stock size and environmental factors on year-class strength in other fish stocks such as the striped bass in the Hudson River. Results of the analyses for each of the three fish stocks are summarized below.

4.5.1 Striped bass

Fourteen environmental variables yielded statistically significant linear regressions for California striped bass, but all were significantly cross-correlated and therefore were statistically redundant. The single best variable for predicting recruitment was percentage of water flow diverted in May (PDM) from the Sacramento-San Joaquin Delta. Linear regression of recruitment against stock was nonsignificant. Multiple linear regression using both stock and PDM as predictors was not significantly better in explaining recruitment variation than linear regression using PDM alone.

Ricker and Beverton-Holt stock-recruitment models had parameter estimates not significantly different from 0.0 and were not appropriate for describing the data. The modified stock-recruitment models (using PDM as the environmental variable) also yielded parameter estimates not significantly different from 0.0 (for at least two out of three parameters), and so they likewise were judged to be inappropriate.

Linear models, therefore, were superior to the other regression models in explaining variation in recruitment for the California striped bass population.

4.5.2 Atlantic menhaden

Ekman transport rates at two sampling stations (1 and 2) were the only environmental variables that yielded significant linear regressions for menhaden recruitment, and these two variables were significantly correlated with each other ($P \leq 0.0003$). Stock size showed no significant linear relationship with recruitment, and multiple regression using both stock size and Ekman transport rate at station 1 (Ekman 1) as predictors showed no significant improvement over linear regression using Ekman 1 alone.

Unmodified stock-recruitment models showed poorer fit [higher residual mean square (RMS) values] to data than did linear models. The Ricker model simplified to linear form due to a parameter estimate not significantly different from 0.0, and the Beverton-Holt model gave negative parameter estimates, which made it biologically uninterpretable.

Two of the modified stock-recruitment models (using Ekman 1 as the environmental variable) reduced to linear form because of parameter estimates not significantly different from 0.0. The third modified stock-recruitment model [Equation (4) in Yoshiyama et al. 1981] gave the second best fit of all models and also was biologically interpretable even though it reduced to a simpler but still nonlinear form. Therefore, it was judged the best model for explaining variation in menhaden recruitment.

4.5.3 American shad

Linear regressions showed that recruitment in American shad was not significantly related to stock size or to either of the two environmental variables examined. Multiple regression of recruitment against log (stock) and the most important environmental variable (logarithm of river discharge rate) showed a noticeable, but nonsignificant, improvement over linear regression of recruitment against log (stock) alone.

The Ricker model showed a better fit to data than did linear models, and its parameter estimates were positive and therefore biologically meaningful, given the premises of the Ricker model. The Beverton-Holt model was no better than linear models and inferior to the Ricker model as a statistical description of the data, and it also gave negative (not biologically valid) parameter estimates.

One modified Ricker model (using the logarithm of river discharge rate as the environmental variable) had two out of three parameters with estimates not significantly different from 0.0, and it therefore was considered an inappropriate description of the data. However, the other modified Ricker model and the modified Beverton-Holt model each had nonzero estimates for all parameters, and they also had lower RMS values than all other models. Thus, relatively complex nonlinear models were the most accurate ones for explaining recruitment variation in American shad.

It is concluded that no one of the three regression approaches was consistently superior in explaining recruitment variation for all three fish stocks. Which approach is judged best in terms of accuracy in describing the data depends in part on the data. However, it seems that general features such as the dependence of variation in striped bass and Atlantic menhaden recruitment upon environmental factors and of variation in American shad recruitment on stock size would be apparent regardless of the details of the regression models and procedures employed.

A few caveats should be noted in interpreting the results of the regression analyses. (a) Some variables of importance to fish recruitment may have been excluded (through oversight or lack of data) from the analyses, and inclusion of such variables could alter the

relative statistical importance of those variables we considered. (b) Measurement error for stock size probably has distorted our results, although it cannot be ascertained what the magnitude of this distortion is. (c) We judged models mainly on the basis of their goodness of fit to the data and secondarily on their biological realism. Although statistical accuracy is probably the most common criterion used in assessing the usefulness of regression models, other criteria (e.g., realism and simplicity) may be of primary concern in some situations.

5. RELATIVE CONTRIBUTION AND DISCRIMINANT ANALYSIS

The question of the contribution of Hudson River striped bass to the Atlantic coastal fishery, relative to the contribution from other areas, was an issue in controversy as early as 1972 when the impacts of Indian Point Unit. No. 2 were being considered. In an attempt to resolve this issue, Texas Instruments, Inc. (TI) conducted an intensive sampling effort in 1975. Discriminant analysis was used to attempt to identify the source of fish collected from coastal regions. Texas Instruments Inc. estimated that the Hudson River contributed approximately 20% of striped bass to the Atlantic coastal fishery, with the Chesapeake believed to supply most of the remainder (Texas Instruments 1976b). After subsequent analysis by TI, the 20% estimate was reduced to 7% (McFadden 1977).

The 1975 TI data were made available to ORNL, and we performed our own discriminant analysis. There was a strong nonlinear relationship between some of the morphological characters and the age of the fish, a relationship which differed among the stocks. This fact was taken into account in an attempt to improve the power of the discriminant functions. It was concluded (Kumar and Van Winkle 1978) that the five-year-old fish which dominated TI's coastal samples originated almost entirely in the Chesapeake as part of the unusually strong 1970 Chesapeake year class. The relative contribution of the Hudson stock varied considerably among year classes, ranging from approximately 10% or less for the 1968 and 1970 year classes up to approximately 30% and greater for the 1965, 1967, and 1971 year classes. A NUREG report describing this work is being prepared (Van Winkle and Kumar, in preparation).

6. CONCLUSIONS AND RECOMMENDATIONS

We have the following conclusions and recommendations, based on our research:

1. For the evaluation of entrainment and impingement impacts, we recommend using empirical models such as the Empirical Transport Model (ETM) and the Empirical Impingement Model (EIM) when sufficient data are available. When sufficient data are not available, it is unlikely that a robust application of such alternatives as hydrodynamic transport models will be possible. In applications of the ETM and the EIM to historical conditions in the Hudson River, it was estimated that the direct impact of entrainment and impingement on striped bass ranged from 7 to 21% in 1974 and 1975. Direct impact estimates from an analysis more representative of future conditions ranged from 11 to 38%.

2. Estimating the entrainment mortality factor (f-factor, defined as the probability that a live organism, entrained in cooling water, will be killed) is difficult. Sampling phenomena should be quantified as much as possible. In general, it is desirable to have comparable sampling conditions at intake and discharge stations. Increasing sample sizes at both intake and discharge sampling stations and increasing the fraction alive in the intake samples (by decreasing sampling mortality) will improve f-factor estimates. We developed and recommend the use of two quantitative tools to aid in designing f-factor sampling programs and in evaluating the results of such programs. The first is a method for determining sample sizes needed to achieve various levels of statistical power in testing f-factor estimates. The second is a computer program, ENTRAN, which can probe the effects of biological and sampling phenomena, and of variation in these phenomena, on the quality of f-factor estimates. Additional research was concerned with indirect mortality, particularly that due to effects of sublethal stress. When direct mortality due to entrainment is less than 100%, it is important to estimate indirect mortality. Application factors accounting for such indirect mortality are recommended, both in setting standards and in modeling population-level impacts.

3. Extreme caution is recommended in relying on models employing compensation functions when making decisions about impacts on populations. There will likely never be sufficient data to adequately parameterize such detailed, mechanistic functions. Stock-recruitment theory represents a potentially attractive alternative. The theory has been extended and adapted for power plant impacts. Further work with the theory will likely produce additional insight. The major unsolved problems, however, are determining the nature of the appropriate relationship and, even more, obtaining reliable estimates of parameter values. Existing stock-recruitment curve fits

cannot be relied on to evaluate compensatory reserve of Hudson River fish populations. The validation technique used to reach this conclusion should be applied to any stock-recruitment curve-fitting exercise for which there is reasonable question about the appropriateness of the data or methodology and on which important decisions depend. Results from three regression approaches for three fish stocks may provide a basis for future assessments of the effects of stock size and environmental factors on year-class strength in other fish stocks such as the striped bass in the Hudson River.

4. Discriminant analysis can be useful in assessing the relative contributions of various regions to a fish stock. It may, however, be possible to improve the power of the discriminant functions by considering the interrelationships among morphological characters, age, sex. and source of the stocks. Using the ORNL discriminant functions, we concluded that the relative contribution of the Hudson stock varied considerably among year classes, ranging from approximately 10% or less for the 1968 and 1970 year classes up to approximately 30% and greater for the 1965, 1967, and 1971 year classes.

7. REFERENCES

Barnthouse, L. W., J. B. Cannon, A. H. Eraslan, J. L. Harris, K. H. Kim, M. E. LaVerne, H. A. McLain, B. D. Murphy, R. J. Raridon, T. H. Row, R. D. Sharp, and W. Van Winkle. 1977. A selective analysis of power plant operation on the Hudson River with emphasis on the Bowline Point Generating Station. ORNL/TM-5877 (Vols. 1 and 2). Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Barnthouse, L. W., D. L. DeAngelis, and S. W. Christensen. 1979. An empirical model of impingement impact. ORNL/NUREG/TM-290 (NUREG/CR-0639). Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Barnthouse, L. W., and W. Van Winkle. 1981. The impact of impingement on the Hudson River white perch population. pp. 199-206. IN L. D. Jensen (ed.), Issues Associated with Impact Assessement: Proceedings of the Fifth National Workshop on Entrainment and Impingement. EA Communications, Sparks, Maryland.

Barnthouse, L. W., W. Van Winkle, J. Golumbek, G. F. Cada, C. P. Goodyear, S. W. Christensen, J. B. Cannon, and D. W. Lee. 1982. Impingement impact analyses, evaluation of alternative screening devices, and critiques of utility analyses relating to density-dependent growth, the age structure of the Hudson River striped bass population, and the LMS Real-Time Life-Cycle Model. Volume II of The Impact of Entrainment and Impingement on Fish Populations in the Hudson River Estuary. ORNL/NUREG/TM-385/V2 (NUREG/CR-2220/V2). Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. Fish. Invest. Minist. Agric. Fish. Food G. B., Ser. II, Salmon Freshwater Fish. 19. 533 pp.

Boreman, J., C. P. Goodyear, and S. W. Christensen. 1978. An empirical transport model for evaluating entrainment of aquatic organisms by power plants. FWS/OBS-78/90. U.S. Fish and Wildlife Service, Ann Arbor, Michigan. 67 pp. + xiii.

Boreman, J., and C. P. Goodyear. 1981. Biases in the estimation of entrainment mortality. pp. 79-89. IN L. D. Jensen (ed.), Issues Associated with Impact Assessment: Proceedings of the Fifth National Workshop on Entrainment and Impingement. Ecological Analysts, Inc., Sparks, Maryland.

Boreman, J., C. P. Goodyear, and S. W. Christensen. 1981. An empirical methodology for estimating entrainment losses at power plants sited on estuaries. Trans. Am. Fish. Soc. 110(2):255-262.

Boreman, J., L. W. Barnthouse, D. S. Vaughan, C. P. Goodyear, S. W. Christensen, K. D. Kumar, B. L. Kirk, and W. Van Winkle. 1982. Entrainment impact estimates for six fish species inhabiting the Hudson River estuary. Volume I of The Impact of Entrainment and Impingement on Fish Populations in the Hudson River Estuary. ORNL/NUREG/TM-385/V1 (NUREG/CR-2220/V1). Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Cada, G. F., J. S. Suffern, K. D. Kumar, and J. A. Solomon. 1981. Investigations of entrainment mortality among larval and juvenile fishes using a power plant simulator. pp. 111-122. IN L. D. Jensen (ed.), Issues Associated with Impact Assessment: Proceedings of the Fifth National Workshop on Entrainment and Impingement. Ecological Analysts, Inc., Sparks, Maryland.

Cannon, T. C., S. M. Jinks, L. R. King, and G. J. Lauer. 1977. Survival of entrained ichthyoplankton and macroinvertebrates at Hudson River power plants. pp. 71-89. IN L. D. Jensen (ed.), Proceedings of the Fourth National Workshop on Entrainment and Impingement. Ecological Analysts, Inc., Melville, New York.

Caswell, H. 1976. Community structure: A neutral model analysis. Ecol. Monogr. 46(3):327-354.

Christensen, S. W. 1977. Quantitative methodologies for estimating the probability of mortality for live organisms entrained by power plants (abstract). Bull. Ecol. Soc. Am. 58(2):39.

Christensen, S. W., D. L. DeAngelis, and A. G. Clark. 1977. Development of a stock-progeny model for assessing power plant effects on fish populations. pp. 196-226. IN W. Van Winkle (ed.), Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations. Pergamon Press, New York. 380 pp.

Christensen, S. W., C. P. Goodyear, and B. L. Kirk. 1979. An analysis of the validity of the utilities' stock-recruitment curve-fitting exercise. Testimony presented before the U.S. Environmental Protection Agency, Region II, in the Matter of Adjudicatory Hearing Docket No. C/II-WP-77-01. 303 pp. + xv.

Christensen, S. W., W. Van Winkle, L. W. Barnthouse, and D. S. Vaughan. 1981. Science and the law: Confluence and conflict on the Hudson River. Environmental Impact Assessment Review 2(1):63-88.

Christensen, S. W., and D. L. DeAngelis. 1982. The effect of stochastic variation on estimates of the probability of entrainment mortality: Methodology, results, and user's guide. ORNL/TM-7965 (NUREG/CR-1830). Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Christensen, S. W., C. P. Goodyear, and B. L. Kirk. 1982. An analysis of the validity of the utilities' stock-recruitment curve-fitting exercise and "prior estimation of beta" technique. Volume III of The Impact of Entrainment and Impingement on Fish Populations in the Hudson River Estuary. ORNL/NUREG/TM-385/V3 (NUREG/CR-2220/V3). Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Christensen, S. W., B. L. Kirk, and C. P. Goodyear. A user's guide for the stock-recruitment model validation program. ORNL/NUREG/TM-8216 (NUREG/CR-2562). Oak Ridge National Laboratory, Oak Ridge, Tennessee. (In preparation).

DeAngelis, D. L., S. W. Christensen, and A. G. Clark. 1977. Responses of a fish population model to young-of-the-year mortality. J. Fish. Res. Board Can. 34(11):2124-2132.

DeAngelis, D. L., and S. W. Christensen. 1979. A general stock-recruitment curve. J. Cons. Cons. Int. Explor. Mer 38(3):324-325.

Ecological Analysts, Inc. (EA). 1977a. A review of entrainment study methodologies: Abundance and survival. Prepared for Empire State Electrical Energy Research Corporation, New York.

Ecological Analysts, Inc. (EA). 1977b. Survival of entrained ichthyoplankton and macroinvertebrates at Hudson River power plants. Prepared for Central Hudson Gas & Electric Corporation, Consolidated Edison Company of New York, Inc., and Orange and Rockland Utilities, Inc., New York.

Eraslan, A. H., W. Van Winkle, R. D. Sharp, S. W. Christensen, C. P. Goodyear, R. M. Rush, and W. Fulkerson. 1976. A computer simulation model for the striped bass young-of-the-year population in the Hudson River. ORNL-NUREG-8 (Special). Oak Ridge National Laboratory, Oak Ridge, Tennessee. 208 pp.

Eraslan, A. H., R. D. Sharp, and W. Van Winkle. 1982. User's manual for STRIPE: A computer code for simulating striped bass young-of-the-year population in the Hudson River. ORNL/NUREG/TM-432 (NUREG/CR-1830). Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Fleiss, J. L. 1973. Statistical Methods for Rates and Proportions. John Wiley and Sons, New York. 223 pp.

Freeman, R. F., and R. K. Sharma. 1977. Survey of fish impingement at power plants in the United States. Volume II. Inland waters. ANL/ES-56. Argonne National Laboratory, Argonne, Illinois.

Gardner, R. H., R. V. O'Neill, J. B. Mankin, and K. D. Kumar. 1980. Comparative error analysis of six predator-prey models. Ecology 61(2):323-332.

Ginn, T. C., G. V. Poje, and J. M. O'Connor. 1977. Survival of planktonic organisms following passage through a simulated power plant condenser tube. pp. 91-101. IN L. D. Jensen (ed.), Proceedings of the Fourth National Workshop on Entrainment and Impingement. Ecological Analysts, Inc., Melville, New York.

Holling, C. S. 1973. Resilience and stability of ecological systems. Annu. Rev. Ecol. and Syst. 4:1-23.

Jinks, S. M., S. D. Jacobson, D. Latimer, and M. E. Loftus. 1981. Advances in techniques for assessment of ichthyoplankton entrainment survival. pp. 91-110. IN L. D. Jensen (ed.), Issues Associated with Impact Assessment: Proceedings of the Fifth National Workshop on Entrainment and Impingement. Ecological Analysts, Inc., Sparks, Maryland.

Kumar, K. D., and W. Van Winkle. 1978. Estimates of relative stock composition of the Atlantic Coast striped bass population based on the 1975 Texas Instruments data set. Northeast Fish and Wildlife Conference, Fisheries and Wildlife Abstracts. American Fisheries Society, Washington, D.C.

Lawler, J. P. 1972a. The effect of entrainment at Indian Point on the population of the Hudson River striped bass. Written testimony presented on April 5, 1972, before the U.S. Atomic Energy Commission in the matter of Consolidated Edison Company of New York, Inc. (Indian Point Station, Unit No. 2).

Lawler, J. P. 1972b. Effect of entrainment and impingement at Indian Point on the population of the Hudson River striped bass, Modifications and additions to testimony of April 5, 1972. Written testimony presented on October 30, 1972, before the U.S. Atomic Energy Commission in the matter of Consolidated Edison Company of New York, Inc. (Indian Point Station, Unit No. 2).

Lawler, J. P. 1974. Effect of entrainment and impingement at Cornwall on the Hudson River striped bass population. Testimony before the Federal Power Commission, USFPC Project No. 2338. Washington, D.C.

Lawler, Matusky & Skelly Engineers (LMS). 1975. Report on development of a real-time two-dimensional model of the Hudson River striped bass population. Prepared under contract with Consolidated Edison Company of New York, Inc, New York.

McFadden, J. T. 1963. An example of inaccuracies inherent in interpretation of ecological field data. Am. Nat. 97:99-116.

McFadden, J. T. (ed.). 1977. Influence of Indian Point Unit 2 and other steam electric generating plants on the Hudson River estuary, with emphasis on striped bass and other fish populations. Submitted to Consolidated Edison Company of New York, Inc., New York.

McFadden, J. T., and J. P. Lawler (eds.). 1977. Supplement I to: Influence of Indian Point Unit No. 2 and other electric generating plants on the Hudson River estuary, with emphasis on striped bass and other fish populations. Prepared for Consolidated Edison Company of New York, Inc., New York.

McGroddy, P. M., and R. L. Wyman. 1977. Efficiency of nets and a new device for sampling living fish larvae. J. Fish. Res. Board Can. 34:571-574.

New York University Medical Center, Institute of Environmental Medicine, Laboratory for Environmental Studies (NYU). 1973. Hudson River ecosystem studies, Effects of entrainment by the Indian Point Power Plant on Hudson River estuary biota. Progress Report for 1971 and 1972. Prepared for Consolidated Edison Company of New York, Inc., New York.

O'Connor, J. M., and S. A. Schaffer. 1977. The effects of sampling gear on the survival of striped bass ichthyoplankton. Ches. Sci. 18(3):312-315.

O'Neill, R. V. 1973. Error analysis of ecological models. pp. 898-908. IN D. J. Nelson (ed.), Radionuclides in Ecosystems. CONF-710501. National Technical Information Service, Springfield, Virginia.

O'Neill, R. V., and R. H. Gardner. 1979. Sources of uncertainty in ecological models. pp. 447-463. IN B. P. Zeigler, M. S. Elzas, G. J. Klir, and T. I. Oren (eds.), Methodology in Systems Modelling and Simulation. North-Holland Publishing Company, Amsterdam.

Ricker, W. E. 1954. Stock and recruitment. J. Fish. Res. Board Can. 11:559-623.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can., Bull. 191. 382 pp.

Schubel, J. R., and B. C. Marcy (eds.). 1978. Power Plant Entrainment: A Biological Assessment. Academic Press, New York. 271 pp.

Sharma, R. K., and R. F. Freeman. 1977. Survey of fish impingement at power plants in the United States. Volume I: The Great Lakes. ANL/ES-56. Argonne National Laboratory, Argonne, Illinois.

Stupka, R. C., and R. K. Sharma. 1977. Survey of fish impingement at power plants in the United States. Volume III. Estuaries and coastal waters. ANL/ES-56. Argonne National Laboratory, Argonne, Illinois. 310 pp.

Swartzman, G. L., R. B. Deriso, and C. Cowan. 1978. Comparison of simulation models used in assessing the effects of power-plant-induced mortality on fish populations. NUREG/CR-0474. University of Washington, Seattle. Prepared for U.S. Nuclear Regulatory Commission.

Texas Instruments, Inc. 1974. Indian Point impingement study report for the period 15 June 1972 through 31 December 1973. Prepared for Consolidated Edison Company at New York, Inc., New York.

Texas Instruments, Inc. 1975a. First annual report for the multiplant impact study of the Hudson River estuary. Prepared for Consolidated Edison Company of New York, Inc., New York.

Texas Instruments, Inc. 1975b. Indian Point impingement study report for the period 1 January 1974 through 31 December 1974. Prepared for Consolidated Edison Company of New York, Inc., New York.

Texas Instruments, Inc. 1976a. Indian Point impingement study report for the period 1 January 1975 through 31 December 1975. Prepared for Consolidated Edison Company of New York, Inc., New York.

Texas Instruments, Inc. 1976b. Report on relative contribution of Hudson River striped bass to the Atlantic Coastal Fishery. Prepared for Consolidated Edison Company of New York, Inc., New York.

Texas Instruments, Inc. 1977. Hudson River ecological study in the area of Indian Point. Annual progress report for 1976. Prepared for Consolidated Edison Company of New York, Inc., New York.

U.S. Nuclear Regulatory Commission (USNRC). 1975. Final environmental statement related to operation of Indian Point Nuclear Generating Plant, Unit No. 3, Consolidated Edison Company of New York, Inc. NUREG-75/002. Two volumes.

Van Winkle, W., S. W. Christensen, and G. Kauffman. 1976. Critique and sensitivity analysis of the compensation function used in the LMS Hudson River striped bass models. ORNL/TM-5437. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 100 pp.

Van Winkle, W., S. W. Christensen, and J. S. Suffern. 1979. Incorporation of sublethal effects and indirect mortality in modeling population-level impacts of a stress, with an example involving power-plant entrainment and striped bass. ORNL/NUREG/TM-288 (NUREG/CR-0638). Oak Ridge National Laboratory, Oak Ridge, Tennessee. 24 pp.

Van Winkle, W., L. W. Barnthouse, B. L. Kirk, and D. S. Vaughan. 1980. Evaluation of impingement losses of white perch at the Indian Point Nuclear Station and other Hudson River power plants. ORNL/NUREG/TM-361 (NUREG/CR-1100). Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Van Winkle, W. and K. D. Kumar. Relative stock composition of the Atlantic coast striped bass population: Further analysis. ORNL/NUREG/TM-8217 (NUREG/CR-2563). Oak Ridge National Laboratory, Oak Ridge, Tennessee (in preparation).

Vaughan, D. S. 1979. Entrainment mortality factors for Hudson River ichthyoplankton at Bowline Point, Lovett, Indian Point, Roseton, and Danskammer Point pwer plants. Chapter VII. IN Boreman, J., L. W. Barnthouse, D. S. Vaughan, C. P. Goodyear, S. W. Christensen, K. D. Kumar, and B. L. Kirk, Entrainment Impact Estimates for Six Fish Populations Inhabiting the Hudson River Estuary. Testimony presented before the United States Environmental Protection Agency, Region II, in the Matter of Adjudicatory Hearing Docket No. C/II-WP-77-01. 125 pp.

Vaughan, D. S., and K. D. Kumar. 1981. Detectability and precision of estimates of entrainment mortality of ichthyoplankton. ORNL/NUREG/TM-435 (NUREG/CR-1984). Oak Ridge National Laboratory, Oak Ridge, Tennessee. 87 pp.

WAPORA, Inc. 1975. Continuing ecological studies of the Ohio River, 1974. Submitted to Appalachian Power Company, Cincinnati Gas and Electric Company, Indiana and Michigan Electric Company, Ohio Edison Company, Ohio Power Company, and Ohio Valley Electric Corporation.

Yoshiyama, R. M., W. Van Winkle, B. L. Kirk, and D. E. Stevens. 1981. Regression analyses of stock-recruitment relationships in three fish populations. ORNL/NUREG/TM-424 (NUREG/CR-1836). Oak Ridge National Laboratory, Oak Ridge, Tennessee. 54 pp.

APPENDIX A: USER'S GUIDE FOR THE FORTRAN IV VERSION OF THE EMPIRICAL TRANSPORT MODEL (ETM)

The FORTRAN IV version of the Empirical Transport Model (ETM) cantains many helpful comment cards. A user who has a listing of the program and a sample input data set, and who has read and understood Boreman et al. (1978 and 1981), should find it relatively easy to operate the program. This Appendix consists mainly of listings of the program, sample input, and the corresponding sample output (Tables A.1, A.2, and A.3, which follow this section). The following notes may be of assistance to users first encountering the program.

1. Comment cards in the program itself explain the meaning of the key terms (see the Glossary in the program).

2. The data in Table A.2 correspond to the base case in Table 9 of Boreman et al. (1978). In this connection, please note that the figure "12.5 percent" which appears in the text of Boreman et al. (1978), both on pages 27 and 30, should read "12.8 percent." The data were structured in a tabular manner, so that in a listing of the data cards (as in Table A.2), the format for the data should be largely self-explanatory.

3. It is necessary, of course, to have the data file structured in accordance to the parameters in the model. Changing certain input parameters will change the number of input data for some other parameters. Comment cards in the program itself provide guidance about this.

4. The program is currently a Type II ETM, corresponding to Eq. (10) in Boreman et al. (1978). Conversion to a Type III ETM [temporally collapsed; Eq. (11) in Boreman et al. (1978)] is easily achieved by following the directions on the appropriate comment cards in the program.

5. Conversion to a Type I ETM [Eq. 6 in Boreman et al. (1978)] would require major restructuring of the program, including expansion of some arrays from two dimensions to three and substantial revision of the data format. In general, the data to support a full Type I ETM will not exist, so we have concentrated our efforts on the more practical Type II version.

6. The program is set up for a time-step (or age-step) measured as weeks. This is embedded in the program, for example in the factor "7" in the main equation and in comment cards and labels for output. Some parameters (e.g., power plant flow rates) have time units of $days^{-1}$ because that is a more common unit for presenting data. The glossary and comment cards, as well as the structure of the data file, should clarify what units are used and needed. If any units are changed (time-step, water volume, etc.), care must be taken to maintain internal consistency.

APPENDIX A: (continued)

7. Some data reduction steps which, in Boreman et al. (1978), were done externally to the model description [e.g., conversion of W-ratio data from a power-plant basis to a region basis in Table 4 in Boreman et al. (1978)] are handled internally in the FORTRAN IV program. [This is also true of the BASIC version which is included in Boreman et al. (1978)].

8. The reference by Boreman et al. (1978) contains some errors. The most relevant ones are identified in the comment cards in the program. In addition, there are some numerical inconsistencies in the development of the "example" data in Boreman et al. (1978). Potential users should therefore not be concerned if they are not able to reproduce each number in that example.

9. The authors urge that the model be used only by persons who have read and understood Boreman et al. (1978 or 1981). Modification of the program itself should only be undertaken by persons who, in addition, are thoroughly comfortable with the actual concepts involved.

Table A.1. Listing of the Empirical Transport Model (ETM)

```
C            ETM - AN EMPIRICAL TRANSPORT MODEL FOR ENTRAINMENT                ETM   1
C                                                                              ETM   2
C          PROGRAM WRITTEN BY S. W. CHRISTENSEN, ENVIRONMENTAL SCIENCES        ETM   3
C          DIVISION, OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TN 37830.       ETM   4
C                                                                              ETM   5
C          LAST REVISED: JANUARY 12, 1982                                      ETM   6
C                                                                              ETM   7
C          REFERENCES:                                                         ETM   8
C          (1) BOREMAN, J., C. P. GOODYEAR, AND S. W. CHRISTENSEN. 1978.       ETM   9
C          AN EMPIRICAL TRANSPORT MODEL FOR EVALUATING ENTRAINMENT OF          ETM  10
C          AQUATIC ORGANISMS BY POWER PLANTS.  FWS/OBS-78/90.                  ETM  11
C          U. S. FISH AND WILDLIFE SERVICE.                                    ETM  12
C          (2) BOREMAN, J., C. P. GOODYEAR, AND S. W. CHRISTENSEN. 1981.       ETM  13
C          AN EMPIRICAL METHODOLOGY FOR ESTIMATING ENTRAINMENT LOSSES AT        ETM  14
C          POWER PLANTS SITED ON ESTUARIES.  TRANS. AM. FISH. SOC.             ETM  15
C          110(2):255-262.                                                     ETM  16
C                                                                              ETM  17
C          THIS IS A TYPE II ETM, CORRESPONDING TO EQ. (10) IN REF. (1)        ETM  18
C          OR EQ. (12) IN REF. (2).  NOTE THAT IN EQ. (10) OF REF. (1),        ETM  19
C          THE SUBSCRIPT "I" UNDER THE FIRST SUMMATION SYMBOL SHOULD BE        ETM  20
C          AN "S."  THIS PROGRAM IS SET UP TO UTILIZE DATA ORIENTED TO         ETM  21
C          LIFE STAGES, RATHER THAN TO AGE, IN ACCORDANCE WITH THE             ETM  22
C          EQUATION ON WHICH IT IS BASED.  THE CODE IS MODIFIED                ETM  23
C          SLIGHTLY TO ACCEPT DATA ORIENTED TO INDIVIDUAL POWER PLANTS,        ETM  24
C          RATHER THAN TO REGIONS.                                             ETM  25
C                                                                              ETM  26
C          INSTRUCTIONS FOR CONVERTING THIS CODE TO A TYPE III ETM             ETM  27
C          ARE CONTAINED IN THE CODE ITSELF IN COMMENT STATEMENTS.             ETM  28
C          THE DATA FOR THIS CODE ARE DESIGNED TO BE SET UP IN                 ETM  29
C          TABULAR FORM, COMPLETE WITH HEADINGS.  THE PROGRAM PRINTS           ETM  30
C          THE INPUT DATA PRIOR TO CALCULATING THE CONDITIONAL                 ETM  31
C          MORTALITY RATE.  THE PROGRAM IS WELL-ENOUGH DOCUMENTED              ETM  32
C          WITH COMMENT CARDS THAT, GIVEN A SAMPLE DATA SET AND                ETM  33
C          ACCESS TO THE REFERENCES, IT SHOULD BE RELATIVELY EASY              ETM  34
C          TO USE.  AS CURRENTLY CONSTRUCTED, THE CODE RUNS ON A               ETM  35
C          DECSYSTEM-10 AND ON AN IBM 3033.                                    ETM  36
C                                                                              ETM  37
C****************************** GLOSSARY ********************************     ETM  38
C                                                                              ETM  39
C                                                                              ETM  40
C             EXCEPT AS NOTED, SINGLE-CHARACTER VARIABLES                      ETM  41
C             IN THIS GLOSSARY CORRESPOND TO THE SAME VARIABLES                ETM  42
C             IN THE REFERENCES.  TWO-CHARACTER VARIABLES                      ETM  43
C             ENDING IN L DENOTE THE "TERMINATOR" VALUES OF                    ETM  44
C             THE INDICES CORRESPONDING TO THE FIRST CHARACTER.                ETM  45
C                                                                              ETM  46
C                                                                              ETM  47
C     C  = AGE-TO-STAGE CONVERSION FACTORS.  FOR A GIVEN AGE, THE              ETM  48
C          SUM ACROSS LIFE STAGES WILL USUALLY BE UNITY AND SHOULD             ETM  49
C          NEVER BE GREATER THAN UNITY.  SEE THE TOP OF PAGE 13                ETM  50
C          IN REF. (1) FOR AN EXAMPLE OF THE USE OF THIS ARRAY (NOTE           ETM  51
C          THAT ERRATA EXIST THAT CORRECT THE SUBSCRIPT NOTATION               ETM  52
C          IN REF. (1) FOR THIS MATERIAL.)  PAGE 256 OF REFERENCE (2)          ETM  53
C          ALSO CONTAINS AN EXAMPLE OF THE USE OF THIS ARRAY.                  ETM  54
C     D  = DISTRIBUTION FACTORS BY LIFE STAGE AND REGION.  FOR A               ETM  55
C          GIVEN LIFE STAGE, THE SUM ACROSS REGIONS MUST BE UNITY.             ETM  56
C     E  = POWER PLANT MORTALITY RATE CONSTANTS BY LIFE STAGE                  ETM  57
C          (UNITS: PER DAY).                                                   ETM  58
C     F  = FRACTION OF ORGANISMS KILLED DUE TO PLANT PASSAGE, BY               ETM  59
C          PLANT AND LIFE STAGE.                                               ETM  60
C     I  = INDEX OF COHORTS (= LOWER-CASE "S" IN THE REFERENCES; SEE           ETM  61
C          INTRODUCTORY COMMENT CARDS ABOVE FOR CORRECTION FOR                 ETM  62
C          EQ. (10) IN REF. (1)).                                              ETM  63
```

REPRODUCED FROM BEST AVAILABLE COPY

Table A.1. (continued)

```
C     II = VALUE OF CURRENT WEEK.                                          ETM  64
C     IL = INDEX OF FINAL COHORT (CAPITAL "S" IN THE REFERENCES).          ETM  65
C          IL MUST BE LESS THAN OR EQUAL TO (NW-JL+1).  THE                ETM  66
C          MAXIMUM VALUE OF NW IS DETERMINED BY THE                        ETM  67
C          FIRST DIMENSION OF E.                                           ETM  68
C     J  = INDEX OF AGE (WEEKS).  SINCE ZERO IS NOT A VALID FORTRAN        ETM  69
C          ARRAY INDEX, THE YOUNGEST AGE IS GIVEN THE INDEX VALUE 1,       ETM  70
C          IN CONTRAST TO REF. (2).                                        ETM  71
C     JL = LAST (OLDEST) ENTRAINABLE AGE.  JL ALSO IS                      ETM  72
C          EQUAL TO THE "ENTRAINMENT INTERVAL" OR THE NUMBER               ETM  73
C          OF "ENTRAINABLE AGES."                                          ETM  74
C     K  = INDEX OF REGION.                                                ETM  75
C     KL = MAXIMUM REGION NUMBER CONSIDERED IN THE MODEL.                  ETM  76
C     L  = INDEX OF LIFE STAGE.                                            ETM  77
C     LL = INDEX VALUE FOR OLDEST ENTRAINABLE LIFE STAGE.                  ETM  78
C     M  = INDEX OF POWER PLANTS.  THIS VARIABLE IS NOT USED AS SUCH       ETM  79
C          IN THE REFERENCES.  HERE, IT IS USED IN CONNECTION WITH         ETM  80
C          CALCULATING E IN SUBROUTINE "PLMORT."  THIS ENABLES             ETM  81
C          POWER PLANT DATA TO BE ENTERED ON A POWER-PLANT-SPECIFIC        ETM  82
C          BASIS, RATHER THAN ON A REGION-SPECIFIC BASIS.                  ETM  83
C     ML = MAXIMUM POWER PLANT NUMBER CONSIDERED IN THE MODEL.             ETM  84
C     NW = NUMBER OF WEEKS OVER WHICH ENTRAINMENT OCCURS.  THIS            ETM  85
C          IS USED TO CONTROL THE NUMBER OF ENTRIES FOR                    ETM  86
C          POWER PLANT FLOWS (SUBROUTINE "INPUT"), AND THE NUMBER OF       ETM  87
C          WEEKS FOR WHICH E IS DEFINED (SUBROUTINE "PLMORT").  IT         ETM  88
C          SHOULD BE CALCULATED AS (IL+JL-1) AND ENTERED IN THE DATA.      ETM  89
C     PP = POWER PLANT WITHDRAWAL FLOWS BY WEEK (UNITS: TCM PER DAY).      ETM  90
C          SEE PW BELOW FOR EXPLANATION.                                   ETM  91
C     PW = POWER PLANT FLOW WITHDRAWAL PROPORTIONS BY REGION.              ETM  92
C          THIS TERM, NOT DEFINED IN THE REFERENCES, PERMITS               ETM  93
C          THE USE OF POWER-PLANT-SPECIFIC P AND W VALUES, RATHER          ETM  94
C          THAN REGION-SPECIFIC VALUES.  FOR A GIVEN POWER PLANT,          ETM  95
C          THE VALUE FOR EACH REGION REPRESENTS THE FRACTION OF THE        ETM  96
C          POWER PLANT'S TOTAL WATER WITHDRAWAL WHICH COMES FROM THAT      ETM  97
C          REGION.  FOR A GIVEN POWER PLANT, THE SUM ACROSS REGIONS        ETM  98
C          MUST BE UNITY.                                                  ETM  99
C          THE PRODUCT OF PW AND PP GIVES P IN REFS. (1) AND (2) (SEE      ETM 100
C          SUBROUTINE "PLMORT").                                           ETM 101
C     R  = FRACTIONAL EGG PRODUCTION BY WEEK.  MUST SUM TO UNITY.          ETM 102
C     V  = REGION VOLUMES (UNITS: THOUSANDS OF CUBIC METERS).              ETM 103
C     W  = POWER PLANT W-RATIOS BY LIFE STAGE.                             ETM 104
C                                                                          ETM 105
      COMMON /BLOCK1/ D(12,5),F(6,5),F(6,5),PP(6,24),E(24,12,5),R(24),PWETM 106
     1(6,12),V(12),C(15,5),ID(80),I,IL,JL,KL,LL,ML,NW                     ETM 107
C     AT PRESENT, DIMENSIONS ARE SET UP FOR:                               ETM 108
C       5  LIFE STAGES (I.E., LL.LE.5)                                     ETM 109
C       6  POWER PLANTS (I.E., ML.LE.6)                                    ETM 110
C       12 REGIONS (I.E., KL.LE.12)                                        ETM 111
C       15 AGES CONSIDERED (I.E., JL.LE.15)                                ETM 112
C       24 WEEKS IN THE SIMULATION, DETERMINED BY THE                      ETM 113
C          DIMENSIONS OF E.  THIS IS THE MAXIMUM VALUE FOR NW.             ETM 114
C                                                                          ETM 115
C.... READ IN INPUT DATA.                                                  ETM 116
      CALL INPUT                                                           ETM 117
      WRITE (6,6) (ID(N),N=61,80)                                          ETM 118
C.... CALCULATE E VALUES.                                                  ETM 119
      CALL PLMORT                                                          ETM 120
      A4=0.                                                                ETM 121
C.... SUM COHORTS OVER SPAWNING WEEKS.                                     ETM 122
      DO 5 I=1,IL                                                          ETM 123
      A3=1.                                                                ETM 124
C.... PRODUCT OF FRACTION SURVIVING THROUGH AGES WITHIN COHORT.            ETM 125
      DO 4 J=1,JL                                                          ETM 126
```

MICROFILMED FROM BEST AVAILABLE COPY

Table A.1. (continued)

```
C.... II = CURRENT WEEK                                                    ETM 127
      II=I+J-1                                                             ETM 128
      A2=1.                                                                ETM 129
C.... PRODUCT OF FRACTION SURVIVING THROUGH APPLICABLE LIFE STAGES         ETM 130
C.... WITHIN AGES.                                                         ETM 131
      DO 3 L=1,LL                                                          ETM 132
      A1=1.                                                                ETM 133
      IF (C(J,L).EQ.0.0) GO TO 2                                           ETM 134
      A1=0.                                                                ETM 135
C.... SUM FRACTIONAL SURVIVAL OVER REGION BY LIFE STAGE WITHIN AGES,       ETM 136
C.... IN FUTURE TIME.                                                      ETM 137
      DO 1 K=1,KL                                                          ETM 138
      IF (D(K,L).EQ.0.0) GO TO 1                                           ETM 139
C.... TO CONVERT THIS TO A "TYPE III" ETM (REF.(1)),                       ETM 140
C.... SUBSTITUTE "1" FOR "II" IN THE NEXT STATEMENT.                       ETM 141
C.... ALSO, READ IN VALUES OF "1" FOR NW AND IL, AND OF                    ETM 142
C.... COURSE ADJUST THE INPUT DATA ACCORDINGLY (I.E., USE ONLY             ETM 143
C.... ONE ROW OF POWER PLANT FLOWS, AND PUT ALL SPAWNING                   ETM 144
C.... IN THE FIRST "WEEK").                                                ETM 145
      A1=A1+D(K,L)*EXP(-E(II,K,L)*7.*C(J,L))                               ETM 146
C.... ENABLING THE NEXT STATEMENT BY REMOVING THE LEADING "C" WILL PRINTETM 147
C.... ONE LINE OF OUTPUT PER PASS THROUGH THE LOOP.  THIS MAY BE           ETM 148
C.... HELPFUL IN DEBUGGING.                                                ETM 149
C     WRITE (6,7) I,J,L,K,A1                                               ETM 150
1     CONTINUE                                                             ETM 151
2     A2=A2*A1                                                             ETM 152
3     CONTINUE                                                             ETM 153
      A3=A3*A2                                                             ETM 154
4     CONTINUE                                                             ETM 155
      A4=A4+A3*R(I)                                                        ETM 156
5     CONTINUE                                                             ETM 157
      A5=1.-A4                                                             ETM 158
      WRITE (6,8) A5                                                       ETM 159
      STOP                                                                 ETM 160
C                                                                          ETM 161
6     FORMAT (///1H ,20A4/)                                                ETM 162
7     FORMAT (1H ,'I=',I2,'  J=',I2,'  L=',I2,'  K=',I2,'  A1=',F10.7)     ETM 163
8     FORMAT (1H0,'THE TOTAL CONDITIONAL MORTALITY RATE IS ',F10.7)        ETM 164
      END                                                                  ETM 165-
      SUBROUTINE INPUT                                                     INP   1
      COMMON /BLOCK1/ D(12,5),F(6,5),W(6,5),PF(6,24),E(24,12,5),R(24),PWINP   2
     1(6,12),V(12),C(15,5),ID(80),I,IL,JL,KL,LL,ML,NW                      INP   3
C.... READ CONTROL VALUES (EXCEPT FOR IL; SEE SPAWNING                     INP   4
C.... PARAMETERS SECTION).                                                 INP   5
      READ (5,7) (ID(N),N=61,80)                                           INP   6
      WRITE (6,8) (ID(N),N=61,80)                                          INP   7
      READ (5,9) (ID(N),N=1,60)                                            INP   8
      WRITE (6,10) (ID(N),N=1,60)                                          INP   9
      READ (5,11) NW,JL,KL,LL,ML                                           INP  10
      WRITE (6,12) NW,JL,KL,LL,ML                                          INP  11
C.... READ INTAKE W-RATIOS.                                                INP  12
      READ (5,13)                                                          INP  13
      WRITE (6,13)                                                         INP  14
      READ (5,9) (ID(N),N=1,60)                                            INP  15
      WRITE (6,10) (ID(N),N=1,60)                                          INP  16
      DO 1 M=1,ML                                                          INP  17
      READ (5,14) (W(M,L),L=1,LL)                                          INP  18
      WRITE (6,15) (W(M,L),L=1,LL)                                         INP  19
1     CONTINUE                                                             INP  20
C.... READ POWER PLANT MORTALITY FACTORS (FRACTION OF ORGANISMS KILLED     INP  21
C.... DUE TO PLANT PASSAGE).                                               INP  22
      READ (5,13)                                                          INP  23
      WRITE (6,13)                                                         INP  24
```

MICROFILMED FROM BEST AVAILABLE COPY

Table A.1. (continued)

```
      READ (5,9) (ID(N),N=1,60)                                    INP  25
      WRITE (6,10) (ID(N),N=1,60)                                  INP  26
      DO 2 M=1,ML                                                  INP  27
      READ (5,14) (F(M,L),L=1,LL)                                  INP  28
      WRITE (6,15) (F(M,L),L=1,LL)                                 INP  29
2     CONTINUE                                                     INP  30
C.... READ PLANT FLOWS.                                            INP  31
      READ (5,13)                                                  INP  32
      WRITE (6,13)                                                 INP  33
      READ (5,9) (ID(N),N=1,60)                                    INP  34
      WRITE (6,10) (ID(N),N=1,60)                                  INP  35
      DO 3 I=1,NW                                                  INP  36
      READ (5,16) (PF(M,I),M=1,ML)                                 INP  37
      WRITE (6,17) (PF(M,I),M=1,ML)                                INP  38
3     CONTINUE                                                     INP  39
C.... READ LIFE-STAGE DISTRIBUTION FACTORS.                        INP  40
      READ (5,13)                                                  INP  41
      WRITE (6,13)                                                 INP  42
      READ (5,9) (ID(N),N=1,60)                                    INP  43
      WRITE (6,10) (ID(N),N=1,60)                                  INP  44
      DO 4 L=1,LL                                                  INP  45
      READ (5,18) (D(K,L),K=1,KL)                                  INP  46
      WRITE (6,19) (D(K,L),K=1,KL)                                 INP  47
4     CONTINUE                                                     INP  48
C.... READ SPAWNING PARAMETERS.                                    INP  49
      READ (5,13)                                                  INP  50
      WRITE (6,13)                                                 INP  51
      READ (5,9) (ID(N),N=1,60)                                    INP  52
      WRITE (6,10) (ID(N),N=1,60)                                  INP  53
      READ (5,20) IL                                               INP  54
      WRITE (6,21) IL                                              INP  55
      READ (5,22) (R(I),I=1,IL)                                    INP  56
      WRITE (6,23) (R(I),I=1,IL)                                   INP  57
C.... READ AGE-TO-STAGE CONVERSION FACTORS.                        INP  58
      READ (5,13)                                                  INP  59
      WRITE (6,13)                                                 INP  60
      READ (5,9) (ID(N),N=1,60)                                    INP  61
      WRITE (6,10) (ID(N),N=1,60)                                  INP  62
      DO 5 J=1,JL                                                  INP  63
      READ (5,24) (C(J,L),L=1,LL)                                  INP  64
      WRITE (6,25) (C(J,L),L=1,LL)                                 INP  65
5     CONTINUE                                                     INP  66
C.... READ REGION VOLUMES.                                         INP  67
      READ (5,13)                                                  INP  68
      WRITE (6,13)                                                 INP  69
      READ (5,9) (ID(N),N=1,60)                                    INP  70
      WRITE (6,10) (ID(N),N=1,60)                                  INP  71
      READ (5,26) (V(K),K=1,KL)                                    INP  72
      WRITE (6,27) (V(K),K=1,KL)                                   INP  73
C.... READ PLANT WITHDRAWAL FRACTIONS BY REGION.                   INP  74
      READ (5,13)                                                  INP  75
      WRITE (6,13)                                                 INP  76
      READ (5,9) (ID(N),N=1,60)                                    INP  77
      WRITE (6,10) (ID(N),N=1,60)                                  INP  78
      DO 6 M=1,ML                                                  INP  79
      READ (5,18) (PW(M,K),K=1,KL)                                 INP  80
      WRITE (6,19) (PW(M,K),K=1,KL)                                INP  81
6     CONTINUE                                                     INP  82
      RETURN                                                       INP  83
C                                                                  INP  84
7     FORMAT (20A4//)                                              INP  85
8     FORMAT (1X,20A4//)                                           INP  86
9     FORMAT (2(20A4/),20A4)                                       INP  87
```

MICROFILMED FROM BEST AVAILABLE COPY

Table A.1. (continued)

```
10    FORMAT (2(1X,20A4/),1X,20A4)                                    INP  88
11    FORMAT (5(8X,I2))                                               INP  89
12    FORMAT (1X,5(8X,I2))                                            INP  90
13    FORMAT (//)                                                     INP  91
14    FORMAT (10X,5(2X,F8.5))                                         INP  92
15    FORMAT (1X,10X,5(2X,F8.5))                                      INP  93
16    FORMAT (10X,6(1X,F9.0))                                         INP  94
17    FORMAT (11X,6(1X,F9.0))                                         INP  95
18    FORMAT (7X,12(F6.0))                                            INP  96
19    FORMAT (8X,12(F6.4))                                            INP  97
20    FORMAT (11X,I2)                                                 INP  98
21    FORMAT (12X,I2)                                                 INP  99
22    FORMAT (F10.8)                                                  INP 100
23    FORMAT (1X,F10.8)                                               INP 101
24    FORMAT (10X,5(2X,F8.7))                                         INP 102
25    FORMAT (11X,5(2X,F8.6))                                         INP 103
26    FORMAT (10X,F10.0)                                              INP 104
27    FORMAT (11X,F10.0)                                              INP 105
      END                                                             INP 106-
      SUBROUTINE PLNORT                                               PLN   1
C.... THIS SUBROUTINE CALCULATES POWER PLANT MORTALITY RATE CONSTANTS. PLN   2
      COMMON /BLOCK1/ D(12,5),F(6,5),W(6,5),PF(6,24),E(24,12,5),R(24),PWPLN   3
     1(6,12),V(12),C(15,5),ID(80),I,IL,JL,KL,LL,ML,NW                 PLN   4
      DO 3 L=1,LL                                                     PLN   5
      DO 2 K=1,KL                                                     PLN   6
      DO 1 II=1,NW                                                    PLN   7
      E(II,K,L)=0.                                                    PLN   8
1     CONTINUE                                                        PLN   9
2     CONTINUE                                                        PLN  10
3     CONTINUE                                                        PLN  11
      DO 7 M=1,ML                                                     PLN  12
      DO 6 L=1,LL                                                     PLN  13
      PP=F(M,L)*W(M,L)                                                PLN  14
      DO 5 K=1,KL                                                     PLN  15
      DO 4 II=1,NW                                                    PLN  16
      P=PF(M,II)*PW(M,K)                                              PLN  17
      E(II,K,L)=E(II,K,L)+(P*PP)/V(K)                                 PLN  18
4     CONTINUE                                                        PLN  19
5     CONTINUE                                                        PLN  20
6     CONTINUE                                                        PLN  21
7     CONTINUE                                                        PLN  22
      RETURN                                                          PLN  23
      END                                                             PLN  24-
```

MICROFILMED FROM BEST AVAILABLE COPY

Table A.2. Sample input data for the Empirical Transport Model (ETM)

```
DATA SET CORRESPONDING TO REFERENCE CASE IN TABLE 9 OF BOREMAN ET AL. 1978.
$
$
                INDEX FOR NUMBER OF
      WEEKS    E. AGES    REGIONS    L. STAGES    PLANTS

       09         05         10          04          05
$
$
$
                    INTAKE/REGION CONCENTRATION RATIOS, BY LIFE STAGE
PLANT          EGG       LARVA      E. JUV    N.E. JUV     EXTRA
              -------   -------    -------   --------   --------
 A             0.5       0.6        0.9       0.0
 B             0.5       0.6        0.9       0.0
 C             0.4       0.8        0.7       0.0
 D             0.4       0.8        0.7       0.0
 E             0.6       0.8         1.       0.0
$
$
$
                    MORTALITY FACTORS DUE TO PLANT PASSAGE, BY LIFE STAGE
PLANT          EGG       LARVA      E. JUV    N.E.JUV      EXTRA
              -------   -------    -------   --------   --------
 A             0.6       0.7        0.8       0.0
 B             0.6       0.7        0.8       0.0
 C             0.6       0.7        0.8       0.0
 D             0.6       0.7        0.8       0.0
 E             0.6       0.7        0.8       0.0
$
$
$
                    PLANT FLOWS IN THOUSAND CUBIC METERS OF WATER PER DAY
              PLANT A   PLANT B   PLANT C   PLANT D   PLANT E   EXTRA
WEEK         -------   -------   -------   -------   -------   -------
 1            3000.     3000.     3000.     6000.     3000.     0.0
 2            3000.     3000.     3000.     6000.     3000.     0.0
 3            3000.     3000.     3000.     6000.     3000.     0.0
 4            3000.     3000.     3000.     6000.     3000.     0.0
 5            3000.     3000.     3000.     6000.     3000.     0.0
 6            3000.     3000.     3000.     3000.     3000.     0.0
 7            3000.     3000.     3000.     3000.     3000.     0.0
 8            3000.     3000.     3000.     3000.     3000.     0.0
 9            3000.     3000.     3000.     3000.     3000.     0.0
$
$
$
                              INPUT OF
                    DISTRIBUTION DATA BY REGION
REGION#<  1 ><  2 ><  3 ><  4 ><  5 ><  6 ><  7 ><  8 ><  9 >< 10 >< 11 >< 12 >
 EGG     0.0   0.0   0.05  0.15  0.35  0.25  0.125 0.075 0.0   0.0   0.0   0.0
 LARVA   0.0   0.1   0.15  0.25  0.25  0.15  0.075 0.025 0.0   0.0   0.0   0.0
 E.JUV   0.0   0.2   0.3   0.2   0.2   0.1   0.0   0.0   0.0   0.0   0.0   0.0
N.E.JUV  0.0   0.3   0.3   0.2   0.2   0.0   0.0   0.0   0.0   0.0   0.0   0.0
$
$
```

MICROFILMED FROM BEST AVAILABLE COPY

Table A.2. (continued)

```
*
SPAWNING  # OF
FRACTION  WEEKS
----------  --
                05
 0.15
 0.20
 0.30
 0.20
 0.15
*
*
*
                    RELATIONSHIP BETWEEN LIFE STAGE AND AGE
AGE             EGG       LARV      P. JUV    N.P. JUV     EXTRA
              --------  --------  --------  --------  --------
  1             1.0       0.        0.        0.
  2             0.        1.        0.        0.
  3             0.        1.0       0.        0.
  4             0.        0.0       1.0       0.
  5             0.        0.        1.0       0.
*
*
*
REGION      VOLUME
NUMBER    (THOUSAND CUBIC METERS)

            ----------
  1         400000.
  2         380000.
  3         360000.
  4         340000.
  5         320000.
  6         300000.
  7         280000.
  8         260000.
  9         240000.
 10         220000.
*
*
*
                                  INPUT OF
                        FRACTIONAL WITHDRAWAL BY REGION
PLANT  <  1 ><  2 ><  3 ><  4 ><  5 ><  6 ><  7 ><  8 ><  9 >< 10 >< 11 >< 12 >
PLANT1    0.0   0.0   0.5   0.5   0.0   0.0   0.0   0.0   0.0   0.0
PLANT2    0.0   0.0   0.0   1.0   0.0   0.0   0.0   0.0   0.0   0.0
PLANT3    0.0   0.0   0.0   0.0   0.0   1.0   0.0   0.0   0.0   0.0
PLANT4    0.0   0.0   0.0   0.0   0.0   1.0   0.0   0.0   0.0   0.0
PLANT5    0.0   0.0   0.0   0.0   0.0   0.0   1.0   0.0   0.0   0.0
PLANT6    0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
```

MICROFILMED FROM BEST AVAILABLE COPY

Table A.3. Model output, using the data in Table A.2 as input. Most of the output consists of a listing of the input data to provide a record for the model user. The conditional mortality rate is given in the last line.

DATA SET CORRESPONDING TO REFERENCE CASE IN TABLE 9 OF BOREMAN ET AL. 1978.

WEEKS	INDEX FOR NUMBER OF E. AGES	REGIONS	L.STAGES	PLANTS
9	5	10	4	5

INTAKE/REGION CONCENTRATION RATIOS, BY LIFE STAGE

PLANT	EGG	LARVA	E. JUV	N.E. JUV	EXTRA
	0.50000	0.60000	0.90000	0.00000	
	0.50000	0.60000	0.90000	0.00000	
	0.40000	0.80000	0.70000	0.00000	
	0.40000	0.80000	0.70000	0.00000	
	0.60000	0.80000	1.00000	0.00000	

MORTALITY FACTORS DUE TO PLANT PASSAGE, BY LIFE STAGE

PLANT	EGG	LARVA	E. JUV	N.E.JUV	EXTRA
	0.60000	0.70000	0.80000	0.00000	
	0.60000	0.70000	0.80000	0.00000	
	0.60000	0.70000	0.80000	0.00000	
	0.60000	0.70000	0.80000	0.00000	
	0.60000	0.70000	0.80000	0.00000	

PLANT FLOWS IN THOUSAND CUBIC METERS OF WATER PER DAY

WEEK	PLANT A	PLANT B	PLANT C	PLANT D	PLANT E	EXTRA
	3000.	3000.	3000.	6000.	3000.	
	3000.	3000.	3000.	6000.	3000.	
	3000.	3000.	3000.	6000.	3000.	
	3000.	3000.	3000.	6000.	3000.	
	3000.	3000.	3000.	6000.	3000.	
	3000.	3000.	3000.	3000.	3000.	
	3000.	3000.	3000.	3000.	3000.	
	3000.	3000.	3000.	3000.	3000.	
	3000.	3000.	3000.	3000.	3000.	

INPUT OF
DISTRIBUTION DATA BY REGION

REGION#<	1 ><	2 ><	3 ><	4 ><	5 ><	6 ><	7 ><	8 ><	9 ><	10 ><	11 ><	12 >
	.0000	.0000	.0500	.1500	.3500	.2500	.1250	.0750	.0000	.0000		
	.0000	.1000	.1500	.2500	.2500	.1500	.0750	.0250	.0000	.0000		
	.0000	.2000	.3000	.2000	.2000	.1000	.0000	.0000	.0000	.0000		
	.0000	.3000	.3000	.2000	.2000	.0000	.0000	.0000	.0000	.0000		

SPAWNING FRACTION	# OF WEEKS
.15000000	5

MICROFILMED FROM BEST AVAILABLE COPY

Table A.3. (continued)

.20000000
.30000000
.20000000
.15000000

RELATIONSHIP BETWEEN LIFE STAGE AND AGE

AGE	EGG	LARV	P. JUV	N.P. JUV	EXTRA
	1.000000	.000000	.000000	.000000	
	.000000	1.000000	.000000	.000000	
	.000000	1.000000	.000000	.000000	
	.000000	.000000	1.000000	.000000	
	.000000	.000000	1.000000	.000000	

REGION NUMBER	VOLUME (THOUSAND CUBIC METERS)
	400000.
	380000.
	360000.
	340000.
	320000.
	300000.
	280000.
	260000.
	240000.
	220000.

INPUT OF
FRACTIONAL WITHDRAWAL BY REGION

PLANT	< 1 ><	2 ><	3 ><	4 ><	5 ><	6 ><	7 ><	8 ><	9 ><	10 ><	11 ><	12 >
	.0000	.0000	.5000	.5000	.0000	.0000	.0000	.0000	.0000	.0000		
	.0000	.0000	.0000	1.0000	.0000	.0000	.0000	.0000	.0000	.0000		
	.0000	.0000	.0000	.0000	.0000	1.0000	.0000	.0000	.0000	.0000		
	.0000	.0000	.0000	.0000	.0000	1.0000	.0000	.0000	.0000	.0000		
	.0000	.0000	.0000	.0000	.0000	1.0000	.0000	.0000	.0000	.0000		

DATA SET CORRESPONDING TO REFERENCE CASE IN TABLE 9 OF DOPEMAN ET AL., 1978.

THE TOTAL CONDITIONAL MORTALITY RATE IS 0.1277699

MICROFILMED FROM BEST AVAILABLE COPY

BLANK PAGE

APPENDIX B: PUBLICATIONS, PRESENTATIONS, AND TESTIMONY

PUBLICATIONS

The following publications were funded in whole or in part by FIN No. B0165 (Methods to Assess Impacts on Hudson River Striped Bass).

Christensen, S. W., W. Van Winkle, and J. S. Mattice. 1976. Defining and determining the significance of impacts: Concepts and methods. pp. 191-219. IN R. K. Sharma, J. D. Buffington, and J. T. McFadden (eds.), The Biological Significance of Environmental Impacts. NR-CONF-002. U.S. Nuclear Regulatory Commission, Washington, D.C. 327 pp.

Eraslan, A. H., W. Van Winkle, R. D. Sharp, S. W. Christensen, C. P. Goodyear, R. M. Rush, and W. Fulkerson. 1976. A computer simulation model for the striped bass young-of-the-year population in the Hudson River. ORNL/NUREG-8 (Special). Oak Ridge National Laboratory, Oak Ridge, Tennessee. 208 pp.

Van Winkle, W. 1976. The applications of computers in an assessment of the environmental impact of power plants on an aquatic ecosystem. IN S. Fernbach and H. M. Schwartz (eds.), Proc., Conference on Computer Support of Environmental Science and Analysis. CONF-750706. U.S. Energy Research and Development Administration, Washington, D.C.

Van Winkle, W., S. W. Christensen, and G. Kauffman. 1976. Critique and sensitivity analysis of the compensation function used in the LMS Hudson River striped bass models. ORNL/TM-5437. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 100 pp.

Christensen, S. W. 1977. Quantitative methodologies for estimating the probability of mortality for live organisms entrained by power plants. Bull. Ecol. Soc. Am. 58(2):39. (Abstract).

Christensen, S. W., D. L. DeAngelis, and A. G. Clark. 1977. Development of a stock-progeny model for assessing power plant effects on fish populations. pp. 196-226. IN W. Van Winkle (ed.), Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations. Pergamon Press, New York. 380 pp.

DeAngelis, D. L., S. W. Christensen, and A. G. Clark. 1977. Responses of a fish population model to young-of-the-year mortality. J. Fish. Res. Board Can. 34(11):2124-2132.

Boreman, J., C. P. Goodyear, and S. W. Christensen. 1978. An empirical transport model for evaluating entrainment of aquatic organisms by power plants. FWS/OBS-78/90. U.S. Fish and Wildlife Service, Ann Arbor, Michigan. 67 pp. + xiii.

APPENDIX B: (continued)

DeAngelis, D. L., W. Van Winkle, S. W. Christensen, S. R. Blum, B. L. Kirk, B. W. Rust, and C. Ross. 1978. A generalized fish life-cycle population model and computer program. ORNL/TM-6125. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 157 pp.

Kumar, K. D., and W. Van Winkle. 1978. Estimates of relative stock composition of the Atlantic Coast striped bass population based on the 1975 Texas Instruments data set. Northeast Fish and Wildlife Conference, Fisheries and Wildlife Abstracts. American Fisheries Society, Washington, D.C.

Van Winkle, W., D. L. DeAngelis, and S. R. Blum. 1978. A density-dependent function for fishing mortality rate and a method for determining elements of a Leslie matrix with density-dependent parameters. Trans. Am. Fish. Soc. 107(3):395-401.

Barnthouse, L. W., D. L. DeAngelis, and S. W. Christensen. 1979. An empirical model of impingement impact. ORNL/NUREG/TM-290 (NUREG/CR-0639). Oak Ridge National Laboratory, Oak Ridge, Tennessee.

DeAngelis, D. L., and S. W. Christensen. 1979. A general stock-recruitment curve. J. Cons. Cons. Int. Explor. Mer 38(3):324-325.

Van Winkle, W., S. W. Christensen, and J. S. Suffern. 1979. Incorporation of sublethal effects and indirect mortality in modeling population-level impacts of a stress, with an example involving power-plant entrainment and striped bass. ORNL/NUREG/TM-288 (NUREG/CR-0638). Oak Ridge National Laboratory, Oak Ridge, Tennessee. 24 pp.

Barnthouse, L. W., S. W. Christensen, B. L. Kirk, K. D. Kumar, W. Van Winkle, and D. S. Vaughan. 1980. Methods to assess impacts on Hudson River striped bass: Report for the period October 1, 1977 to September 30, 1979. ORNL/NUREG/TM-374 (NUREG/CR-1243). Oak Ridge National Laboratory, Oak Ridge, Tennessee. 27 pp.

DeAngelis, D. L., L. J. Svoboda, S. W. Christensen, and D. S. Vaughan. 1980. Stability and return times of Leslie matrices with density-dependent survival: Applications to fish populations. Ecol. Model. 8:149-163.

Boreman, J., C. P. Goodyear, and S. W. Christensen. 1981. An empirical methodology for estimating entrainment losses at power plants sited on estuaries. Trans. Am. Fish. Soc. 110(2):255-262.

APPENDIX B: (continued)

Christensen, S. W., W. Van Winkle, L. W. Barnthouse, and D. S. Vaughan. 1981. Science and the law: Confluence and conflict on the Hudson River. Environmental Impact Assessment Review 2(1):63-88.

Vaughan, D. S., and K. D. Kumar. 1981. Detectability and precision of estimates of entrainment mortality of ichthyoplankton. ORNL/NUREG/TM-435 (NUREG/CR-1984). Oak Ridge National Laboratory, Oak Ridge, Tennessee. 87 pp.

Yoshiyama, R. M., W. Van Winkle, B. L. Kirk, and D. E. Stevens. 1981. Regression analyses of stock-recruitment relationships in three fish populations. ORNL/NUREG/TM-424 (NUREG/CR-1836). Oak Ridge National Laboratory, Oak Ridge, Tennessee. 54 pp.

Barnthouse, L. W., W. Van Winkle, J. Golumbek, G. F. Cada, C. P. Goodyear, S. W. Christensen, J. B. Cannon, and D. W. Lee. 1982. Impingement impact analyses, evaluation of alternative screening devices, and critiques of utility analyses relating to density-dependent growth, the age structure of the Hudson River striped bass population, and the LMS Real-Time Life-Cycle Model. Volume II of The Impact of Entrainment and Impingement on Fish Populations in the Hudson River Estuary. ORNL/NUREG/TM-385/V2 (NUREG/CR-2220/V2). Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Boreman, J., L. W. Barnthouse, D. S. Vaughan, C. P. Goodyear, S. W. Christensen, K. D. Kumar, B. L. Kirk, and W. Van Winkle. 1982. Entrainment impact estimates for six fish species inhabiting the Hudson River estuary. Volume I of The Impact of Entrainment and Impingement on Fish Populations in the Hudson River Estuary. ORNL/NUREG/TM-385/V1 (NUREG/CR-2220/V1). Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Christensen, S. W., and D. L. DeAngelis. 1982. The effect of stochastic variation on estimates of the probability of entrainment mortality: Methodology, results, and user's guide. ORNL/TM-7965 (NUREG/CR-2533). Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Christensen, S. W., C. P. Goodyear, and B. L. Kirk. 1982. An analysis of the validity of the utilites' stock-recruitment curve-fitting exercise and "prior estimation of beta" technique. Volume III of The Impact of Entrainment and Impingement on Fish Populations in the Hudson River Estuary. ORNL/NUREG/TM-385/V3 (NUREG/CR-2220/V3). Oak Ridge National Laboratory, Oak Ridge, Tennessee.

APPENDIX B: (continued)

Eraslan, A. H., R. D. Sharp, and W. Van Winkle. 1982. User's manual for STRIPE: A computer code for simulating striped bass young-of-the-year population in the Hudson River. ORNL/NUREG/TM-423, (NUREG/CR-1830). Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Christensen, S. W., B. L. Kirk, and C. P. Goodyear. A user's guide for the stock-recruitment model validation program. ORNL/NUREG/TM-8216 (NUREG/CR-2562). Oak Ridge National Laboratory, Oak Ridge, Tennessee (in preparation).

Van Winkle, W. and K. D. Kumar. Relative stock composition of the Atlantic Coast striped bass population: Further analysis. ORNL/NUREG/TM-8217. (NUREG/CR-2563). Oak Ridge National Laboratory, Oak Ridge, Tennessee (in preparation).

APPENDIX B: (continued)

PRESENTATIONS

The following presentations were funded in whole or in part by FIN No. B0165 (Methods to Assess Impacts on Hudson River Striped Bass).

Christensen, S. W., W. Van Winkle, and J. S. Mattice, "Defining and determining the significance of impacts: Concepts and methods," Workshop on the Biological Significance of Environmental Impacts, Ann Arbor, Michigan, June 1975.

Van Winkle, W., "Impact assessment, Indian Point, and striped bass," Applied Ecology Course, Special Training Division, Oak Ridge Assoicated Universities, Oak Ridge, Tennessee, July 1975.

Van Winkle, W., "The application of computers in an assessment of the environmental impact of power plants on an aquatic ecosystem," ERDA-Wide Conference on Computer Support of Environmental Science and Analysis, Albuqerque, New Mexico, July 1975.

Van Winkle, W., "Impact assessment, Indian Point, and striped bass," Systems Ecology Seminar, University of Tennessee, Knoxville, October 1975.

Van Winkle, W., "Benefit to the striped bass fisheries of cooling towers at Indian Point," Environmental Statements Project Information Meeting, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October 1975.

Van Winkle, W., "Introductory remarks" and "Conclusions and recommendations for assessing the population-level effects of power plant exploitation: The optimist, the pessimist, and the realist," Conference on Assessing the Effects of Power-Plant-Induced Mortality in Fish Populations, Gatlinburg, Tennessee, May 1977.

Christensen, S. W., "Development of a stock-progeny model for assessing power plant effects on fish populations," Conference on Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations, Gatlinburg, Tennessee, May 1977.

Christensen, S. W., "Quantitative methodologies for estimating the probability of mortality for live organisms entrained by power plants," Annual Meeting, American Institute of Biological Sciences, East Lansing, Michigan, August 1977.

Kirk, B. L., "Maximum entropy spectral analysis of biological population time series," 1977 Fall Meeting, Society for Industrial and Applied Mathematics, Albuquerque, New Mexico, November 1977.

APPENDIX B: (continued)

Van Winkle, W., "The Hudson River power plant case: Scientific issues in controversy," Fisheries Laboratory, Lowestoft, England, November 1977, and Fisheries Department, Food and Agriculture Organisation, Rome, Italy, November 1977.

Van Winkle, W., "Modeling techniques for predicting long-term consequences of the effects of radiation on natural aquatic populations and ecosystems," and "Statistical considerations appropriate for radiation effects experiments," International Atomic Energy Agency Group Advisory Meeting, Vienna, Austria, November 1977.

Kumar, K., "Estimates of relative stock composition of the Atlantic Coast striped bass population based on the 1975 Texas Instruments data set," 1978 Northeastern Fish and Wildlife Conference, White Sulfur Springs, West Virginia, February 1978.

Christensen, S. W., "Science and the law: Confluence and conflict on the Hudson River," Presentation at the Environmental Sciences Division Annual Information Meeting, Oak Ridge National Laboratory, Oak Ridge, Tennessee, April 1978.

Barnthouse, L. W., "Dynamic models of an aquatic multispecies system," Annual Meeting, American Institute of Biological Sciences, Athens, Georgia, August 1978.

Christensen, S. W., Organized and moderated a module on "Entrainment of fish by power plants," 108th Annual Meeting, American Fisheries Society, University of Rhode Island, Kingston, Rhode Island, August 1978.

Boreman, J., C. P. Goodyear, and S. W. Christensen, "An empirical transport model for evaluating entrainment of aquatic organisms by power plants," 108th Annual Meeting, American Fisheries Society, University of Rhode Island, Kingston, Rhode Island, August 1978.

Van Winkle, W., "Comparison of methods of analyzing stock-recruit data using California striped bass data," Seminar presented at the Center for Quantitative Science in Forestry, Fisheries, and Wildlife, University of Washington, Seattle, October 1978; also presented at the California Department of Fish and Game, Stockton, California, October 1978.

Christensen, S. W., "An approach to validating stock-recruitment curve fits," 109th Annual Meeting, American Fisheries Society, West Yellowstone, Montana, September 1979.

Vaughan, D. S., "Detectability and precision of estimates of entrainment mortality of icthyoplankton," 109th Annual Meeting, American Fisheries Society, West Yellowstone, Montana, September 1979.

APPENDIX B: (continued)

Barnthouse, L. W., "Population models in impact assessment: The lesson of the Hudson River Power Case," Environmental Sciences Division Annual Information Meeting, Oak Ridge, Tennessee, May 1981.

Christensen, S. W., and D. L. DeAngelis, "Effect of environmental variation on reliability of entrainment mortality estimates," 111th Annual Meeting, American Fisheries Society, Albuquerque, New Mexico, September 1981.

APPENDIX B: (continued)

TESTIMONY

The following testimony was not funded by FIN No. B0165 (Methods to Assess Impacts on Hudson River Striped Bass), but it was funded in whole or in part by the U.S. Nuclear Regulatory Commission and made use of the methodologies developed by this project.

Christensen, S. W., W. Van Winkle, and P. C. Cota. 1975. Effect of Summit Power Station on striped bass populations. Testimony before the Atomic Safety Licensing Board in the Matter of Summit Power Station, Units 1 and 2, Delmarva Power and Light Co. and Philadelphia Electric Co., USAEC Docket Nos. 50-450 and 50-451, March 1975. 104 pp.

Spore, R., and W. Van Winkle. 1977. Testimony of NRC staff on the relative benefits and costs associated with applicant's request for extension of operation with once-through cooling at Indian Point Unit No. 2. Testimony before the Atomic Safety and Licensing Board in the matter of Consolidated Edison Company of New York, Inc., Indian Point Station, Unit No. 2, Docket No. 50-247, February 1977.

Van Winkle, W. 1977. Supplemental testimony of NRC staff in response to Board comments on aquatic impact analysis. Testimony before the Atomic Safety and Licensing Board in the matter of Consolidated Edison Company of New York, Inc., Indian Point Station, Unit No. 2, Docket No. 50-247, February 1977.

Barnthouse, L. W. 1979. An analysis of factors that influence impingement estimates at Hudson River power plants. Testimony presented before the United States Environmental Protection Agency, Region II, in the Matter of Adjudicatory Hearing Docket No. C/II-WP-77-01, May 1979. 50 pp.

Barnthouse, L. W. 1979. Density-dependent growth: A critique of the utilities' "empirical evidence." Testimony presented before the United States Environmental Protection Agency, Region II, in the Matter of Adjudicatory Hearing Docket No. C/II-77-01, May 1979. 46 pp.

APPENDIX B: (continued)

Barnthouse, L. W., K. D. Kumar, and B. L. Kirk. 1979. W-factors for Hudson River ichthyoplankton entrained at Bowline, Lovett, Indian Point, Roseton, and Danskammer. Chapter V. 76 pp. IN J. Boreman, L. W. Barnthouse, D. S. Vaughan, C. P. Goodyear, S. W. Christensen, K. D. Kumar, and B. L. Kirk, Entrainment Impact Estimates for Six Fish Populations Inhabiting the Hudson River Estuary. Testimony presented before the United States Environmental Protection Agency, Region II, in the Matter of Adjudicatory Hearing Docket No. C/II-WP-77-01, May 1979.

Barnthouse, L. W., and W. Van Winkle. 1979. Impingement impact estimates for seven Hudson River fish species. Testimony presented before the United States Environmental Protection Agency, Region II, in the Matter of Adjudicatory Hearing Docket No. C/II-WP-77-01, April 1979. 93 pp.

Boreman, J., C. P. Goodyear, and S. W. Christensen. 1979. Mathematical methods used in estimating conditional entrainment mortality rates of six Hudson River fish populations. Chapter I. 12 pp. IN J. Boreman, L. W. Barnthouse, D. S. Vaughan, C. P. Goodyear, S. W. Christensen, K. D. Kumar, and B. L. Kirk, Entrainment Impact Estimates for Six Fish Populations Inhabiting the Hudson River Estuary. Testimony presented before the United States Environmental Protection Agency, Region II, in the Matter of Adjudicatory Hearing Docket No. C/II-WP-77-01, May 1979.

Christensen, S. W., C. P. Goodyear, and B. L. Kirk. 1979. An analysis of the validity of the utilities' stock-recruitment curve-fitting exercise. Testimony presented before the United States Environmental Protection Agency, Region II, in the Matter of Adjudicatory Hearing Docket No. C/II-WP-77-01, May 1979. 303 pp. + xv.

Golumbek, J., and S. W. Christensen. 1979. A critical review of the utilities' age composition analysis of the Hudson River striped bass population. Testimony presented before the United States Environmental Protection Agency, Region II, in the Matter of Adjudicatory Hearing Docket No. C/II-WP-77-01, May 1979. 30 pp.

Golumbek, J., W. Van Winkle, and C. P. Goodyear. 1979. A critical evaluation of the Lawler, Matusky and Skelly two-dimensional real-time life cycle model of the Hudson River striped bass population. Testimony presented before the United States Environmental Protection Agency, Region II, in the Matter of Adjudicatory Hearing Docket No. C/II-WP-77-01, May 1979. 66 pp.

APPENDIX B: (continued)

Van Winkle, W., and L. W. Barnthouse. 1979. Evaluation of impingement losses of white perch at Hudson River power plants. Testimony presented before the United States Environmental Protection Agency, Region II, in the Matter of Adjudicatory Hearing Docket No. C/II-WP-77-01, April 1979. 63 pp.

Van Winkle, W., and S. W. Christensen. 1979. Incorporation of sublethal effects and indirect mortality in modeling population-level impacts of power-plant entrainment. Testimony presented before the United States Environmental Protection Agency, Region II, in the Matter of Adjudicatory Hearing Docket No. C/II-WP-77-01. 5 pp.

Vaughan, D. S. 1979. Entrainment mortality factors for Hudson River ichthyoplankton at Bowline Point, Lovett, Indian Point, Roseton, and Danskammer power plants. Chapter VII. 125 pp. IN J. Boreman, L. W. Barnthouse, D. S. Vaughan, C. P. Goodyear, S. W. Christensen, K. D. Kumar, and B. L. Kirk, Entrainment Impact Estimates for Six Fish Populations Inhabiting the Hudson River Estuary. Testimony presented before the United States Environmental Protection Agency, Region II, in the Matter of Adjudicatory Hearing Docket No. C/II-WP-77-01, May 1979.

NUREG/CR-2674
ORNL/TM-8309
Distribution Category-RE

INTERNAL DISTRIBUTION

1. S. I. Auerbach
2-5. L. W. Barnthouse
6. J. E. Breck
7. G. F. Cada
8-11. S. W. Christensen
12. C. C. Coutant
13. D. L. DeAngelis
14. M. P. Farrell
15. S. G. Hildebrand
16. D. W. Lee
17. J. M. Loar
18. A. L. Lotts
19. R. B. McLean
20. R. M. Rush
21-24. W. Van Winkle
25-28. D. S. Vaughan
29. N. D. Vaughan
30. G. T. Yeh
31. Central Research Library
32-43. ESD Library
44-45. Laboratory Records Dept.
46. Laboratory Records, ORNL-RC
47. ORNL Y-12 Technical Library
48. ORNL Patent Office

EXTERNAL DISTRIBUTION

49. P. Hayes, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC 20555
50. Office of Assistant Manager for Energy Research and Development, DOE-ORO
51-52. Technical Information Center, Oak Ridge, TN 37830
43-277. NRC distribution - RE (Environmental Research)

SPECIAL DISTRIBUTION BY NRC

278. J. H. Balletto, Licensing and Environment Department, Public Service Electric and Gas Company, 80 Park Plaza, Newark, NJ 07101
279. H. L. Bergman, Department of Zoology and Physiology, The University of Wyoming, University Station, P.O. Box 3166, Laramie, WY 82071
280. K. E. Biesinger, Environmental Research Laboratory - Duluth, 6201 Congdon Blvd., Duluth, MN 55804
281. C. W. Billups, U.S. Nuclear Regulatory Commission, Washington, DC 20555
282. J. G. Boreman, Northeast Fisheries Center, National Marine Fisheries Service, Woods Hole, MA 02543
283. W. H. Bossert, Harvard University, Cambridge, MA 02138
284. R. W. Brocksen, Electric Power Research Institute, P.O. Box 10412, Palo Alto, CA 94303
285. H. W. Brown, American Electric Power Service Corporation, P.O. Box 487, Canton, OH 44701
286. E. J. Carpenter, Marine Sciences Research Center, State University of New York, Stony Brook, NY 11794

287. H. K. Chadwick, California Department of Fish and Game, 3900 N. Wilson Way, Stockton, CA 95204
288. C. Chen, Tetra Tech, Inc., 3700 Mt. Diablo Blvd., LaFayette, CA 94549
289. B. Cohen, U.S. Environmental Protection Agency, Region II, 26 Federal Plaza, Room 845, New York, NY 10278
290. M. J. Dadswell, Biological Station, Fisheries and Oceans Canada, St. Andrews, New Brunswick, CANADA
291. R. Deriso, International Pacific Halibut Commission, P.O. Box 5009, University Station, Seattle, WA 98105
292. Margaret Dilling, Librarian, Ichthyological Associates, Inc., 100 South Cass Street, Middletown, DE 19709
293. D. J. Dunning, Power Authority of the State of New York, 10 Columbus Circle, New York, NY 10019
294. Ecological Analysts, Inc., Library, R.D. 2, Goshen Turnpike, Middletown, NY 10940
295. C. Edwards, International Joint Commission, Regional Office, 100 Ouellette Avenue, Windsor, Ontario N9A 6T3, CANADA
296. T. Englert, Lawler, Matusky, and Skelly Engineers, 415 Route 303, Tappan, NY 10983
297. T. K. Fikslin, U.S. Environmental Protection Agency, Woodbridge Avenue, Edison, NJ 08817
298. R. I. Fletcher, Center for Quantitative Science, University of Washington, Seattle, WA 98195
299. T. D. Fontaine, III, Savannah River Ecology Laboratory, Drawer E, Aiken, SC 29801
300. A. A. Galli, U.S. Environmental Protection Agency, Mail Code R.D. 682, Washington, DC 20460
301. H. Gluckstern, Regional Counsel and Enforcement Division, U.S. Environmental Protection Agency, Region II, 26 Federal Plaza, Room 441, New York, NY 10278
302. R. A. Goldstein, Electric Power Research Institute, P.O. Box 10412, Palo Alto, CA 94303
303. J. Golumbek, Energy and Thermal Wastes Section, Water Division, U.S. Environmental Protection Agency, Region II, New York, NY 10278
304. C. P. Goodyear, National Fisheries Center-Leetown, U.S. Fish and Wildlife Service, Route 3, P.O. Box 41, Kearnysville, WV 25430
305. P. A. Hackney, Division of Forestry, Fisheries, and Wildlife Development, Tennessee Valley Authority, Norris, TN 37828
306. D. H. Hamilton, Office of Health and Environmental Research, Department of Energy, Germantown, MD 20767
307. R. Henshaw, Bureau of Environmental Protection, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233
308. C. Hickey, U.S. Nuclear Regulatory Commission, Washington, DC 20555
309. Frank F. Hooper, Ecology, Fisheries and Wildlife Program, School of Natural Resources, The University of Michigan, Ann Arbor, MI 48109

310. E. G. Horn, Chief, Bureau of Environmental Protection, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233
311. T. Horst, Environmental Engineering Division, Stone and Webster Engineering Corp., 225 Franklin St., Boston, MA 02107
312. T. Huggins, Central Hudson Gas and Electric Corporation, 284 South Avenue, Poughkeepsie, NY 12602
313. J. B. Hutchison, Jr., Orange and Rockland Utilities, Inc., 75 West Rt. 59, Spring Valley, NY 10977
314. B. L. Kirk, 1608 Helmboldt Road, Knoxville, TN 37919
315. W. L. Kirk, Consolidated Edison, 4 Irving Place, New York, NY 10003
316. R. J. Klauda, Applied Physics Laboratory, The Johns Hopkins University, Johns Hopkins Road, Laurel, MD 20810
317. L. C. Kohlenstein, Applied Physics Laboratory, The Johns Hopkins University, Johns Hopkins Road, Laurel, MD 20810
318. K. D. Kumar, SAS Institute, SAS Circle, P.O. Box 8000, Cary, NC 27511
319. G. J. Lauer, Ecological Analysts, Inc., R.D. 2, Goshen Turnpike, Middletown, NY 10940
320. R. Levins, Harvard School of Public Health, Harvard University, Boston, MA 02115
321. S. Lewis, U.S. Nuclear Regulatory Commission, Office of the Executive Legal Director, Washington, DC 20555
322. F. Locicero, Technical Resources Branch, U.S. Environmental Protection Agency, Region II, 26 Federal Plaza, New York, NY 10278
323. Helen McCammon, Director, Division of Ecological Research, Office of Health and Environmental Research, Office of Energy Research, MS-E201, ER-75, Room F-322, Department of Energy, Washington, DC 20545
324. D. McKenzie, Ecosystems Dept., Battelle Pacific Northwest Laboratory, Richland, WA 99352
325. G. Milburn, U.S. Environmental Protection Agency, Region V, Enforcement Division, 230 S. Dearborn St., Chicago, IL 60604
326. J. Miner, Ecological Analysts, Inc., 221 Oak Creek Drive, Lincoln, NE 68528
327. S. Moore, Resources Management Associates, 3706 Mt. Diablo Blvd., LaFayette, CA 94549
328. M. Mulkey, Office of the General Counsel, U.S. Environmental Protection Agency, 4th and M Street, SW, Washington, DC 20460
329. W. Muller, New York Institute of Technology, Old Westbury, NY 11568
330. Haydn H. Murray, Director, Department of Geology, Indiana University, Bloomington, IN 47405
331. J. V. Nabholz, Office of Toxic Substances, Environmental Review Division, Environmental Protection Agency, 401 M Street, SW, Washington, DC 20545
332. William S. Osburn, Jr., Division of Ecological Research, Office of Health and Environmental Research, Office of Energy Research, Department of Energy, Washington, DC 20545

333. C. H. Pennington, Waterways Experiment Station, P.O. Box 631, Vicksburg, MS 39180
334. T. T. Polgar, Martin Marietta Laboratories, 1450 S. Rolling Rd., Baltimore, MD 21227
335. D. Policansky, University of Massachusetts, Boston, MA 02125
336. E. M. Portner, The Johns Hopkins University, Applied Physics Laboratory, Johns Hopkins Rd., Laurel, MD 20810
337. E. Radle, Bureau of Environmental Protection, New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY 12233
338. P. Rago, School of Natural Resources, University of Michigan, Ann Arbor, MI 48109
339. W. E. Ricker, Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, British Columbia V9R 5K6, CANADA
340. Paul G. Risser, Office of the Chief, Illinois Natural History Survey, Natural Resources Building, 607 E. Peabody Ave., Champaign, IL 61820
341. D. S. Robson, Biometrics Unit, Cornell University, Ithaca, NY 14850
342. F. J. Rohlf, State University of New York, Stony Brook, NY 11790
343. Q. E. Ross, Power Authority of the State of New York, 10 Columbus Circle, New York, NY 10019
344. S. Saila, Department of Zoology, University of Rhode Island, Kingston, RI 02881
345. E. Santoro, Technical Resources Branch, U.S. Environmental Protection Agency, Region II, 26 Federal Plaza, New York, NY 10278
346. W. E. Schaaf, Atlantic Estuarine Fisheries Center, National Marine Fisheries Service, Beaufort, NC 28516
347. C. N. Shuster, Jr., Office of Energy Systems, Federal Energy Regulatory Commission, 825 N. Capitol St., Washington, DC 20426
348. M. P. Sissenwine, National Marine Fisheries Service, Woods Hole, MA 02543
349. P. N. Skinner, New York State Law Department, Two World Trade Center, New York, NY 10047
350. L. B. Slobodkin, State University of New York, Stony Brook, NY 11790
351. J. Strong, Regional Counsel and Enforcement Division, U.S. Environmental Protection Agency, Region II, 26 Federal Plaza, Room 441, New York, NY 10278
352. David Swan, Vice President, Environmental Issues, Kennecott Corporation, Ten Stamford Forum, P.O. Box 10137, Stamford, CT 06904
353. G. Swartzman, Center for Quantitative Science, University of Washington, Seattle, WA 98195
354. L. Tebo, U.S. Environmental Protection Agency, Southeast Environmental Research Laboratory, College Station Road, Athens, GA 30601
355. K. W. Thornton, Environmental Laboratory, United States Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS 39180

356. C. J. Walton, Maine Department of Marine Resources, Fisheries Research Laboratory, West Boothbay Harbor, ME 04575
357. R. L. Watters, Division of Ecological Research, Office of Health and Environmental Research, Department of Energy, Washington, DC 20546
358. A. W. Wells, Ichthyological Associates, Inc., Delaware River Ecological Study, 100 South Cass St., Middletown, DE 19709
359. Frank J. Wobber, Division of Ecological Research, Office of Health and Environmental Research, Office of Energy Research, MS-E201, Department of Energy, Washington, DC 20545
360. Robert W. Wood, Director, Division of Pollutant Characterization and Safety Research, Department of Energy, Washington, DC 20545
361. Ronald M. Yoshiyama, 1794 Isabella Ave., Monterey Park, CA 91754

END